New Water Treatment System at the Freshwater Institute: Description and Performance Evaluation After One Year of Operation (1985/86)

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NEW WATER TREATMENT SYSTEM AT THE FRESHWATER INSTITUTE: DESCRIPTION AND PERFORMANCE EVALUATION AFTER ONE YEAR OF OPERATION (1985/86)

by

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ABSTRACT

Wagemann, R., E. Scherer, and J. Czwarno. 1987. New water treatment system at the Freshwater Institute: description and performance evaluation after one year of operation (1985/86). Can. Manuscr. Rep. Fish. Aquat. Sci. 1919: iv + 31 p.

A new water system was installed at the Freshwater Institute in 1985 to remove chlorine from the Winnipeg City tap water without the addition of chemicals, and to make the final product water suitable for toxicity and physiological studies involving aquatic organisms. A number of chemical constituents were monitored at various points in the new system on a weekly basis over the first year of operation. Chlorine was monitored daily at four different sampling sites. Its concentration in the final product water was, with few exceptions when operational adjustments took place, at or below target value throughout the year.

Some bacterial production of nitrogenous compounds occurred in the system, but the concentration of these constituents was still well below target or anticipated levels.

The activated carbon filters approached saturation with regard to dissolved organic constituents after approximately four months of operation.

Dissolved copper, and zinc concentrations were reduced consistently and manganese less consistently by the system below target or anticipated levels in the final product water. The system did not consistently reduce dissolved iron or aluminium to desired levels.

Key words: water purification; dechlorination; trace elements; detoxification; bioassay.

RÉSUMÉ

Wagemann, R., E. Scherer, and J. Czwarno. 1987. New water treatment system at the Freshwater Institute: description and performance evaluation after one year of operation (1985/86). Can. Manuscr. Rep. Fish. Aquat. Sci. 1919: iv + 31 p.

Un nouveau système de traitement de l'eau a été installé à l'Institut des eaux douces en 1985 pour enlever le chlore de l'eau du robinet fourni par la Ville de Winnipeg sans addition de produit chimique afin que l'eau traitée puisse se prêter aux études toxicologiques et physiologiques avec des de organismes aquatiques. Un certain nombre de paramètres chimiques ont été contrôlés chaque semaine à divers points dans le nouveau système au cours de cette première année. On a prélevé des échantillons tous les jours, à quatre points différents, afin de déceler la présence de chlore; sauf dans les cas où des modifications étaient apportées au système, la concentration de chlore dans l'eau traitée a été égale ou inférieure à la concentration visée tout au long de l'année.

Il y a eu production bactérienne de composés azoteux dans le système, mais la concentration de ces composés était bien inférieure aux valeurs prévues ou visées.

Après environ quatre mois, les composés organiques dissous avaient à peu près saturé les filtres à charbon actif.

Le système a permis de réduire le cuivre dissous et les concentrations de zinc dans l'eau traitée de façon systématique en deçà des valeurs prévues ou visées, ce qui n'a pas toujours été le cas pour le manganèse; enfin, le niveau de fer et d'aluminium dissous n'a pu être abaissé systématiquement au niveau souhaité.

Mots-clés: purification de l'eau; déchloration; oligo-éléments; désintoxication; bio-essai.

INTRODUCTION

The Freshwater Institute (FWI) draws on Winnipeg tap water for all its needs. The main FWI building was completed in 1972. It had a water treatment system for holding, culturing and experimenting with aquatic organisms, which consisted of anthracite and sand bed filters, a degassifier, and cooling and heating facilities to provide 10°C water. Chlorine was removed chemically, by the continuous, metered addition of excess sodium thiosulfate (Pyle 1960; McCauley and Scott 1960). The thiosulfate and its metal complexes in the product water limited its usefulness for physiological and metal toxicity studies. Moreover, it became apparent with time that residual chlorine and other chemical constituents tended to fluctuate significantly in the treated water. At certain times of the year, zooplankton and algae from Shoal Lake (the source of Winnipeg's water supply) or a city reservoir would pass through the system filters and appear in product water. During summer months the water temperature could not be maintained reliably at 10°C by this system. The need for an additional low-temperature line arose to facilitate work with Arctic species at the FWI. More stringent water quality guidelines, criteria and standards for physiological and toxilogical studies evolved internationally during the 1970's.

All these considerations led to a substantially upgraded, redesigned water treatment system which was put into service in September, 1985.

MAJOR SYSTEM COMPONENTS

Removal of chlorine is accomplished by physical and photochemical processes without the addition of any chemicals. The major components of the system and their functional connections are outlined in Fig. 1.

MIXED MEDIA FILTERS

These consist of two (1.83 m diam.) steel tanks lined with 10 mm of plasite® material, connected in series. They contain Neptune MF-Microflow 186 mixed filter media, consisting of 55% coal (specific gravity S.G. 1.4), 30% silica sand (S.G. 2.6), and 15% high density sand (S.G. 4.0). The gravel and sand form the support bed for the coal layer, and stabilize the coal interface. The total thickness of the mixed media bed is 1.5 m. These filters are backwashed once every week for 20 minutes, at a flow rate of 1320 L/min.

OZONATION SYSTEM

Ozone is produced in a separate system (Waste Disposal Bldg) by pumping air into cells with electrodes at a potential of 300 V DC. The capacity of this system (i.e. ozone/air flow rate from this system) is 280 L/min (i.e., 0.28 m^3/min) containing 1% ozone. The air-ozone mixture is injected at the rate of 110 L/min into each of two stainless steel mixing tanks (1.5 m diam. X 2.5 m height), connected in parallel.

VERTICAL ACTIVATED CARBON FILTERS

Two steel tanks (2.13 m diam.) lined with 10 mm of plasite® material, connected in series, contain a bed, 1.5 m deep, of Calgon "Filtrasorb 300" activated carbon. This is underlaid by a support bed of sand. A third such filter tank is on standby, and is used during weekly backwashing.

ULTRA-VIOLET IRRADIATION

Consists of three stainless steel tanks, each containing 8 to 10 Unitech Ultra-violet lamps (L58 UTL), with a rated lifetime of 9000 hours/lamp.

Deposits on lamps (probably iron and manganese oxides) reduce light output after two to four weeks of operation. These deposits are removed by pumping citric acid solution (0.06 M) through the tanks (while they are isolated from the rest of the system), once in every three weeks.

DEGASSIFIERS (GAS BALANCING TOWERS)

These consist of two fiberglass tanks, (1.83 m diam. X 6.7 m height), connected in parallel. They are filled with 38 mm polypropylene Raschig rings, over which water flows from top to bottom against a stream of air. The air is drawn from the immediate vicinity of the tanks, but is first filtered through high-efficiency fiberglass (300x600x300 mm, rigid cartridge type) filters.

PRODUCT WATER FILTERS

These are nylon fabric sleeves (9 cm diam. X 94 cm long), sized for 10 micron particle size retention, mounted in stainless steel containers.

PIPING

The various components in the integrated old and new piping system are connected either by type 304 stainless steel, PVC, or polypropylene pipe (prime grade unimpregnated resin, specifically manufactured for distilled water systems). Washers are all of Teflon®.

TARGET AND ANTICIPATED VALUES

"Target" values for various chemicals for the new water treatment system (Table 1) were provided to the design engineers for their guidance at an early stage of the project. They are essentially "safe, no-effect-to-most-organisms"

limits, derived largely from data in the scientific literature (APHA 1980; ASTM 1975, 1978, 1982; Wedemeyer and Yasutake 1977; NAS 1972; McKee and Wolf 1963), as reviewed by FWI physiologists and toxicologists. "Anticipated" values are essentially system performance estimates anticipated by design engineers, and considered acceptable by users.

SAMPLING AND CHEMICAL ANALYSES

Samples were collected for chemical analyses once a week (Thursday p.m.), from three different points in the system (Stations 1,4,9, Fig. 1). For residual chlorine analysis, samples were also collected daily (Monday to Friday a.m. and p.m.), and additionally from Station 3.

Residual chlorine was measured spectrophotometrically (10 cm path length) by the orthotolidine method (APHA 1971). The minimum detectable concentration was 1 µg/L. Five chromate-dichromate standards, in the concentration range 1-25 µg/L were used to calibrate the instrument, and phosphate buffer was used as a blank.

For trace metal analysis, samples were collected in 500 mL polyethylene bottles, cleaned by soaking overnight in 10% nitric acid followed by three rinses with deionized water. (New bottles were soaked overnight in a detergent solution prior to acid washing). Trace metals were measured by flameless atomic absorption (graphite furnace) on unfiltered samples, using a Varian 975 AA with GTA-95 furnace. Diluted Fisher AA standards were used for instrument calibration.

The methods given in the FWI manual (Stainton et al. 1977) were used for the determination of all other constituents listed.

PERFORMANCE

CHLORINE (Fig. 2, 3, 4, 5, 6)

Chlorine was measured daily at four different points in the system namely, at the point where City water entered the system, prior to any treatment (Station 1), after ozonation but before carbon filtration (Station 3), after carbon filtration (Station 4), and after all treatments, i.e. the finished product water in a laboratory, (Station 9), Fig. 1.

A graphical comparison (on the same scale) of daily chlorine concentrations in untreated (City water) and in the final product water (Fig. 2), shows quite clearly the great reduction in chlorine achieved by the system.

After the first six months of operation, the system began to meet consistently the performance criteria for chlorine as shown in Fig. 3, where once-weekly (Thursday p.m.) values are plotted. The chlorine concentration was most of the time at or below the target value of 3 µg/L, and was consistently below the anticipated value of 15 µg/L. During the first six months of operation, when the system was still equilibrating, the target value was frequently exceeded, but the anticipated value was seldom exceeded.

A fractional reduction of chlorine up to 85% by mixed media filtration and ozonation (Fig. 4) was achieved at optimal performance. Shortly after the system was brought fully on stream, ozonation had to be discontinued for operational reasons, for four months (November 26, 1985 to the end of February, 1986). Although no sharp discontinuity in chlorine removal occurred as a result of this interruption in ozonation, some reduction in the efficiency of removal at Station 3 is evident during this time period, (Fig. 4). There was then a steady improvement in the efficiency of chlorine removal from 50 to 85% after ozonation resumed up to July, 1986; thereafter the efficiency declined again at Station 3 to nearly 70% by September, 1986.

Activated carbon filtration produced a reduction of approximately 85% at peak performance (between Stations 3 and 4) up to the end of April, 1986. Thereafter, the performance of the carbon filters declined somewhat, (Fig. 5). The total reduction in chlorine at this point in the system compared to City water (i.e. Station 4 relative to Station 1), was 93-97%. The reduction between Station 4 and Station 9 was 65-99% of the remaining Cl_2, Fig. 6, achieved largely by uv-irradiation, (Armstrong and Scott 1974; Giles and Danell 1983). However, the total reduction in chlorine in final product water relative to that in City water (i.e. between Station 1 and Station 9) was practically 100%.

RESIDUAL CHLORINE IN RELATION TO FLOW RATE

The maximum sustainable flow rate of the system is 600 L/min. During the first year of operation the system operated at half its capacity on average (Table 2). The chemical data reported here pertain to this lower-than-maximum flow rate. Estimates of water turnover times for the systems for various flow rates are listed in Table 3. When flow was increased on two occasions for test purposes, the chlorine concentration in product water increased: October 1-2, 1985; chlorine increased from <1 µg/L to >6 µg/L when the flow rate was 660 L/min; November 4-8, 1985, chlorine increased from 5 µg/L to 16 µg/L when the flow rate was 700 L/min. Thereafter, it took four days to return to pre-test chlorine levels.

NON-IONIZED AMMONIA (Fig. 7)

The ammonia concentration was consistently higher in the final product water than in untreated City water. Some ammonia was obviously being produced within the system, very likely as a result of bacterial growth, possibly within the activated carbon filtration units. Although the filtration system was being backwashed once every week, ammonia production within the system

persisted. However, the concentration of ammonia in product water was always less than the target value of 5 µg/L during the year.

NITRITE AND NITRATE (Fig. 8 and 9)

As with ammonia, nitrite and nitrate concentrations were generally higher in the product water than in City water. The nitrite concentration was consistently below the target value of 20 µg/L, but exceeded frequently the anticipated value of 1 µg/L throughout the year.

The nitrate concentration consistently exceeded the target value of 10 µg/L, and the anticipated value of 1 µg/L was achieved on only three occasions during the year. From a toxicological point of view, this does not appear to pose a problem, since nitrate is not known to be toxic to most organisms even at the highest concentrations (up to 100 µg/L) that were encountered in product water during the year.

TRACE METALS: Al, Cu, Fe, Mn, Zn (Fig. 10, 11, 12, 13, 14)

There was no consistent reduction of dissolved aluminium achieved by the water treatment system, Fig. 10. The target value of 1 µg/L in the final product water was exceeded throughout the year, except once, and the anticipated value of 5 µg/L was exceeded about half of the time.

Some reduction in the concentration of copper was achieved consistently by the system. The copper concentration in City water was generally at or slightly below the target value of 1 µg/L, and the copper concentration in the final product water was below that value throughout the year, (Fig. 11), except once, when the concentration in incoming water was relatively high.

Despite some reduction by the system, the dissolved iron concentration in the final product water was consistently higher than the target value of 1 µg/L, and was also higher than the anticipated value of 10 µg/L, (Fig. 12).

The water treatment system reduced effectively but not consistently the manganese concentration in the water. The dissolved manganese concentration in the final product water was significantly lower than in City water; it was frequently at and occasionally below the anticipated value of 2 µg/L (Fig. 13). No target value was promulgated for manganese.

The zinc concentration was already quite low in City water (< 0.4 µg/L), and this was further reduced somewhat by the system (Fig. 14). The zinc concentration in the final product water, therefore never exceeded the target value of 1 µg/L.

MAJOR IONS (Na, K, Ca, Mg, Cl, SO_4)

The major ions were monitored for a period of approximately three and a half months (August 22, 1985 to December 12, 1985). The system had no effect on these ions. Concentrations in product water were essentially the same as in City water namely: 1.8-2.2 mg/L Na^+; 1.2-1.4 mg/L K^+; 20-24 mg/L Ca^{++}; 5.1-6.4 mg/L Cl^-; 3.3-3.9 mg/L SO_4^{--}.

TOTAL DISSOLVED P, C, N (Fig. 15, 16, 17)

The system had no effect on dissolved phosphorus, which remained practically the same in the final product water as in City water throughout the year, Fig. 15.

Total dissolved carbon, Fig. 16, and total dissolved nitrogen (organically derived only), Fig. 17, were both drastically lower in final product water than in City water during the first two to four months of operation. The system effectively removed these components from City Water during the initial phase of operation. Thereafter the concentration of these components in the final product water progressively increased, until in July, 1986, they were practically at the same level as in City water. These components were presumably being removed largely by the activated carbon filters. It would appear that these filters became saturated and ineffective with regard to these components after approximately four months of operation.

CARBON DIOXIDE AND DISSOLVED INORGANIC CARBON (Fig. 18 and 19)

Excess carbon dioxide was effectively removed from City water in the gas balancing towers when the concentration in City water was relatively high. The level in the final product water was maintained in the range 20 - 35 µM, which was still somewhat above saturation with atmospheric carbon dioxide (9 µM at 10°C).

The water treatment system had no significant effect on total dissolved inorganic carbon.

PARTICULATE: Fe, C, N, P (Fig. 20, 21, 22, 23)

The concentration of suspended particulate matter was effectively reduced by the system to relatively low levels in the final product water, except when filtration was occasionally interrupted as a consequence of maintenance or additional installation work being performed on the system.

TOTAL SUSPENDED SOLIDS (Fig. 24)

The concentration of total suspended solids in City water never exceeded the target (10 mg/L) or anticipated (5 mg/L) values. The concentration in the final product water did not exceed 1 mg/L throughout the year, and was frequently lower than this. The system reduced effectively the concentration of total suspended matter, particularly when it was substantially higher than 1 mg/L in City water.

CONCLUSIONS AND OUTLOOK

The new water treatment system performed better than expected during its first year of operation in that chlorine was effectively removed from the water. The concentration of chlorine in the final product water was reduced below the target value (<3 µg/L) when the system was performing optimally, and was reduced below the anticipated value (<15 µg/L) most of the time. Occasionally, somewhat higher values were observed, but this was traced to operational disruptions and adjustments to the system.

Dissolved copper and zinc were maintained at or below target (1 µg/L), and manganese was maintained most of the time at or below the anticipated value (2 µg/L). For dissolved iron and aluminium, the concentrations in the final product water always exceeded target and anticipated values, notwithstanding some reduction in dissolved iron by the system. However, according to McNeely et al., 1979, safe levels for freshwater organisms are <300 µg/L Fe and <100 µg/L Al.

The system was effective in reducing total suspended solids well below the target value (5 µg/L).

Dissolved organic compounds were effectively removed during the first two months of operation. After four months, reduction was only approximately 20%, indicating that some progressive de-activation of carbon filters may have taken place during this time.

All numerical data for the period in question are on file, in the form of a data report, in the FWI library, and are available on request.

The fluoride concentration in product water was not monitored. The City of Winnipeg fluoridates its water supply to the level of approximately 1 ppm. Since the system has no capacity to remove fluoride (such a feature was incorporated at the design stage but was removed by Treasury Board at the approval stage), this was presumably the approximate concentration of fluoride in the final product water. Fluoride will undoubtedly cause problems in some toxicity experiments, either because of toxicity to some sensitive organisms (Sigler and Neuhold 1972), or because of complex formation with some metals, e.g. Al. Further improvements to the water treatment system that would remove fluoride from City water (e.g. reverse osmosis) will then have to be considered.

To provide some guidance to operations personnel on the life expectancy of the renewable components in the system, monitoring of some selected parameters should be continued for at least another year.

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Table 1. Target and anticipated values for various chemical components prescribed in the design brief (Reid Crowther and Partners Ltd. 1983) for the new water treatment system.

Parameter	Target	Anticipated
pH (units)	7-8	7.4
Hardness (mg/L $CaCO_3$)	80*	80
Alkalinity (mg/L $CaCO_3$)	75*	75
Conductivity (umho/cm)	165*	165
Suspended Solids (mg/L), (μ)	<80, 10	<5, <10
Residual Chlorine (μg/L)	<3	10-15
T.O.C. (mg/L)	<2	-
C.O.D. (mg/L)	<5	-
Ammonia, (non-ionized) (μg/L)	<5	<5
Nitrite (μg/L NO_2)	<20	1
Nitrate (μg/L NO_3)	<10	<1
Aluminium (μg/L)	<1	<5
Arsenic (μg/L)	<1	<1
Cobalt (μg/L)	<1	<2
Chromium (μg/L)	<1	-
Copper (μg/L)	<1	<3
Iron (μg/L)	<1	10
Manganese (μg/L)	-	2
Lead (μg/L)	<1	<1
Selenium (μg/L)	-	<1
Nickel (μg/L)	<1	<2
Zinc (μg/L)	<1	<1
Cadmium (μg/L)	<0.1	<0.1
Mercury (μg/L)	<0.1	-
Silver (μg/L)	<0.1	-
Boron (μg/L)	<100	-
Fluoride (μg/L)	<100	920
Total Organophosphorous Pesticides (ng/L)	<50	<10
Total Organochlorine Pesticides + PCB's (ng/L)	<50 (OCP's + PCB's)	<10 (OCP's)
Total HC's C<10. (μg/L) (Aromatic and Aliphatic)	-	27
CCl_4 (μg/L)	-	Tr.
$CHCl_3$ (μg/L)	-	<20
$CHCl_2$(μg/L)	-	<20

- indicates no data available.
* the same as in Shoal Lake, Winnipeg's water source.

Table 2. Average flow rates of treated water.

	1985	1986
	- - - - - L/min - -	- -
January	-----	316.5
February	-----	295.4
March	-----	271.8
April	-----	226.6
May	-----	239.8
June	-----	235.5
July	-----	252.4
August	522.2	290.3
September	380.9	279.2
October	340.2	304.0
November	386.4	285.3
December	339.8	314.8

Table 3. Replacement times for 50% to 99% of the water in the system at various flow rates, assuming a system volume of 10 000 gal. (45 500 L).

Flow rate	- - - - - - - Replacement time, hours - - - - - - -				
L/min	50% repl.	75% Repl.	90% Repl.	95% Repl.	99% Repl.
150	3.5	7.0	12	15	23
200	2.6	5.3	8.7	12	18
250	2.1	4.2	7.0	9.1	14
300	1.8	3.5	5.8	7.6	12
350	1.5	3.0	5.0	6.5	10
400	1.3	2.6	4.4	5.7	8.7
500	1.1	2.1	3.5	4.5	7.0
600	0.9	1.8	2.9	3.8	5.8

FWI WATER TREATMENT SYSTEM (1985) (SAMPLING STATIONS)

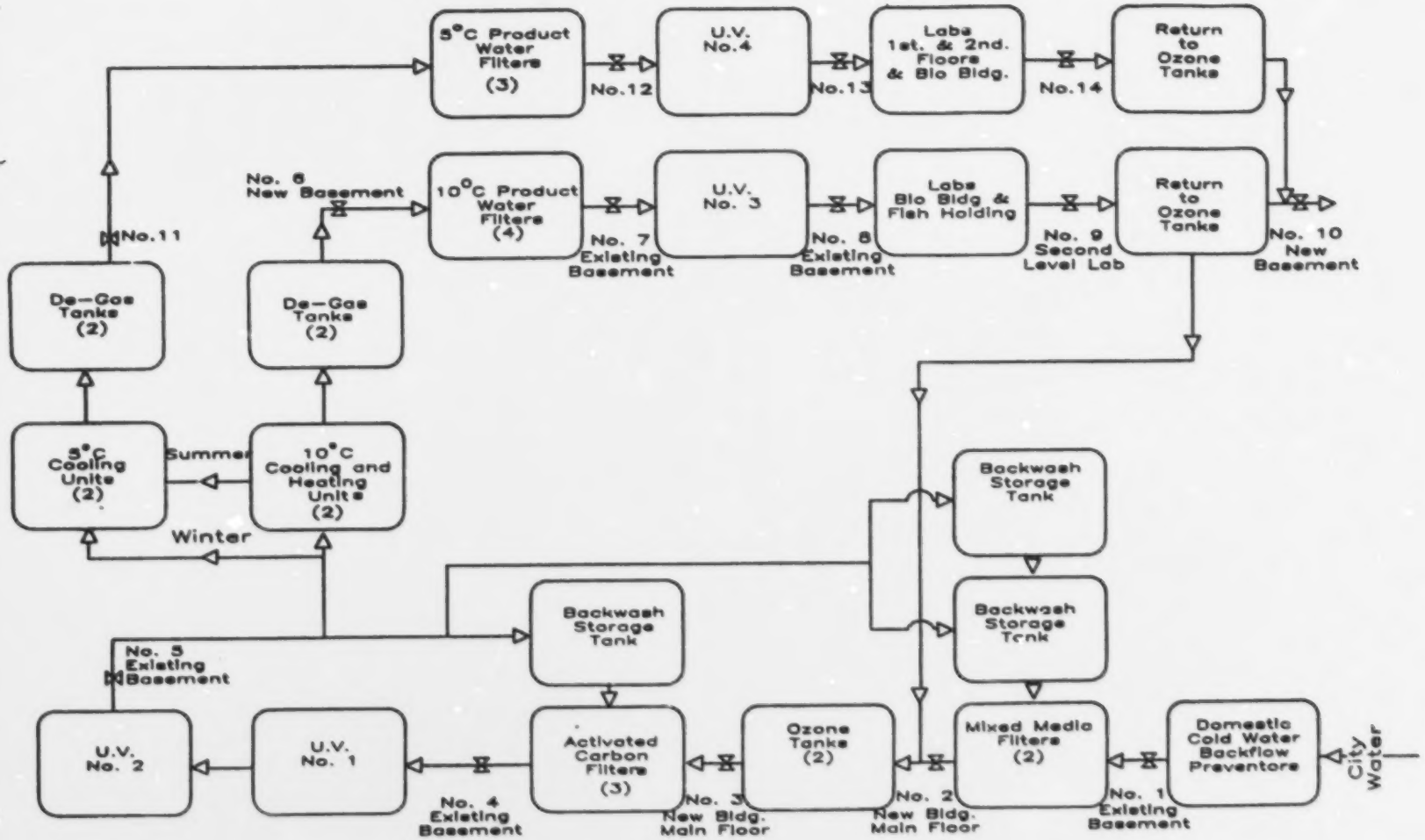

Fig. 1. Schematic of FWI Water Treatment System. Water samples were taken for analysis at stations 1, 3, 4 and 9. Sampling stations are indicated by numbers between component blocks.

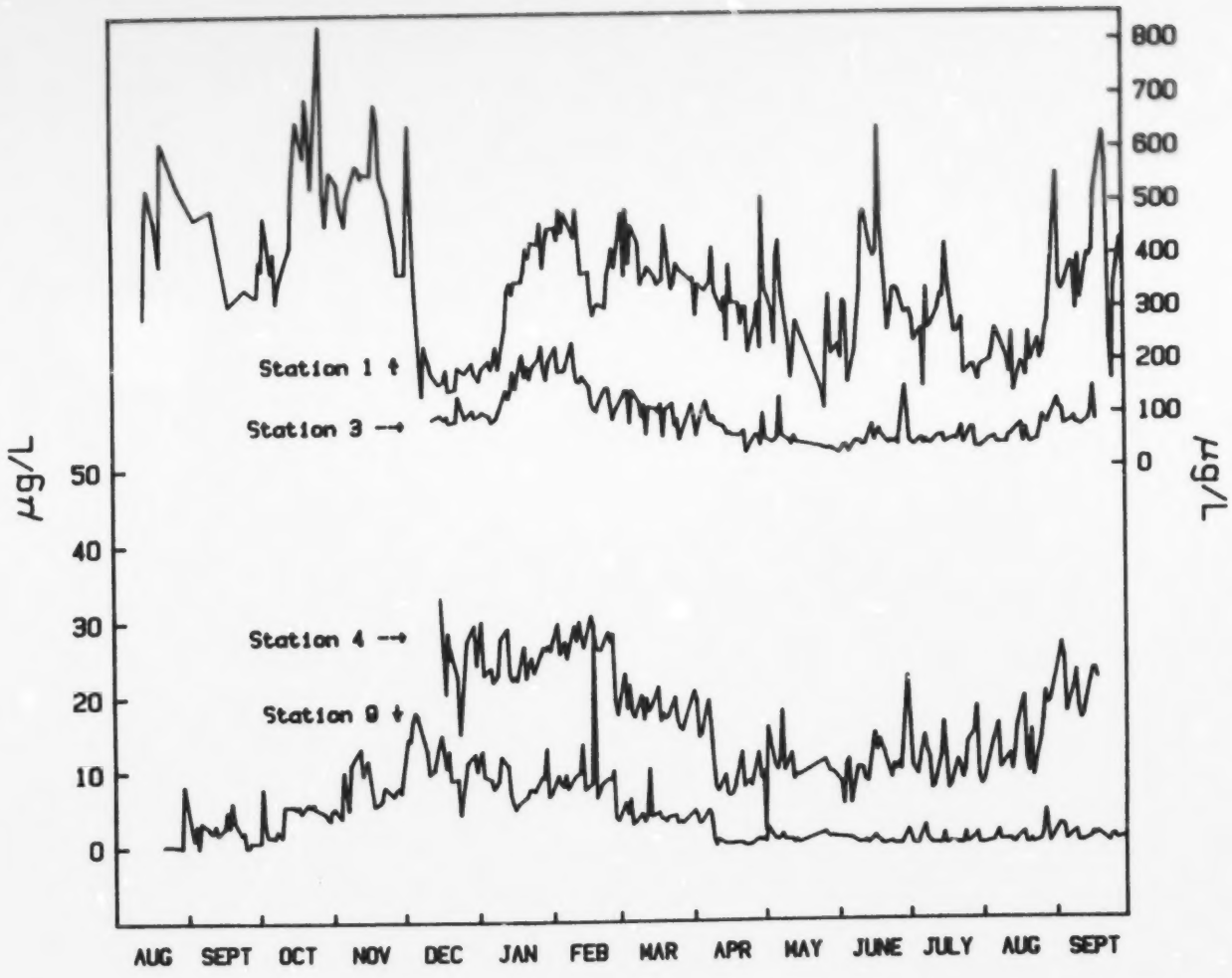

Fig. 2. Daily chlorine concentrations in product water (Stn.9), City water (Stn.1), and before and after carbon filters, Stations 3 and 4, 1985/86.

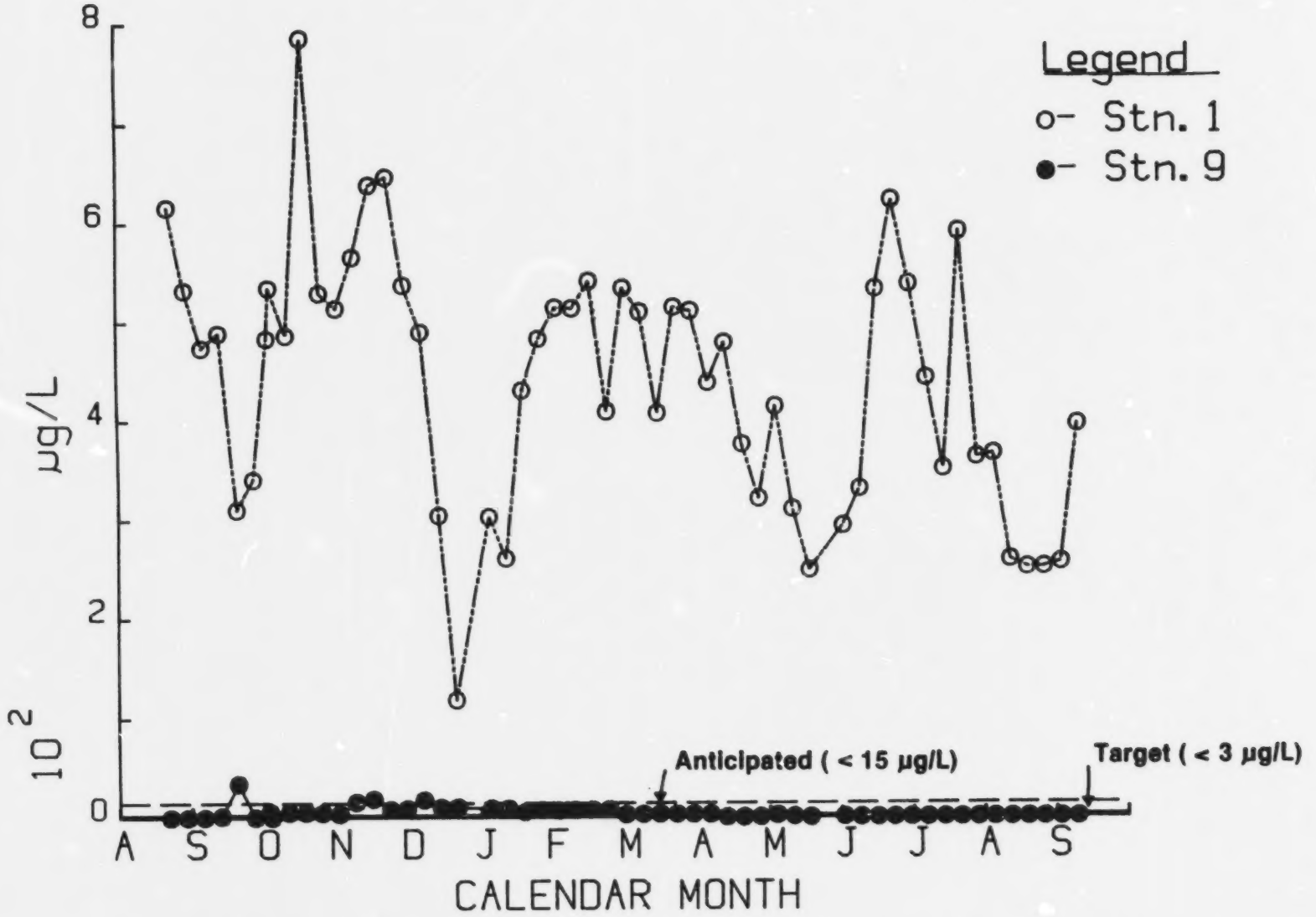

Fig. 3. Once-weekly chlorine concentrations in product water (Stn 9) and City water (Stn 1), 1985/86.

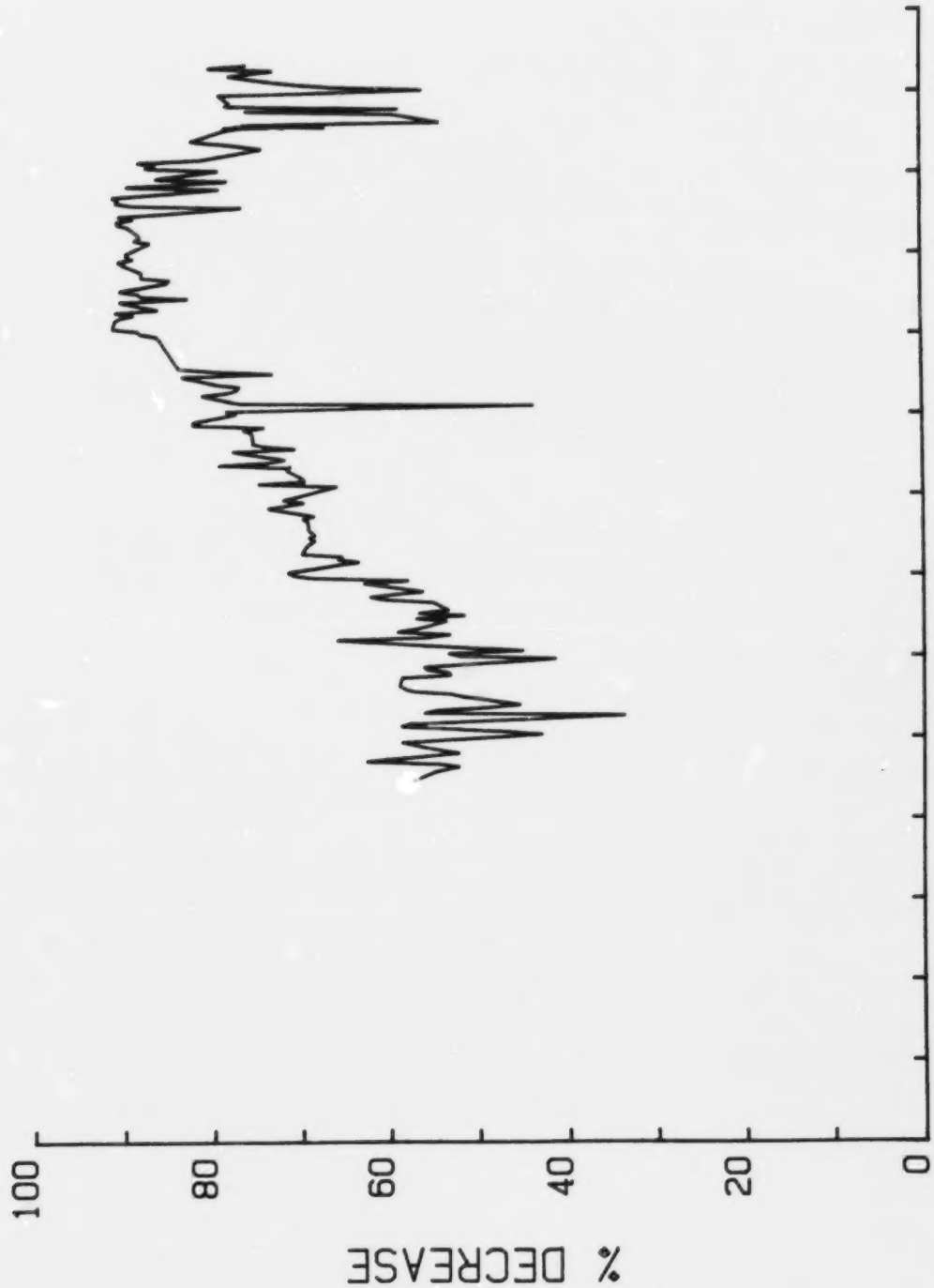

Fig. 4. Relative decrease of chlorine between Stn 1 and Stn 3, 1985/86.

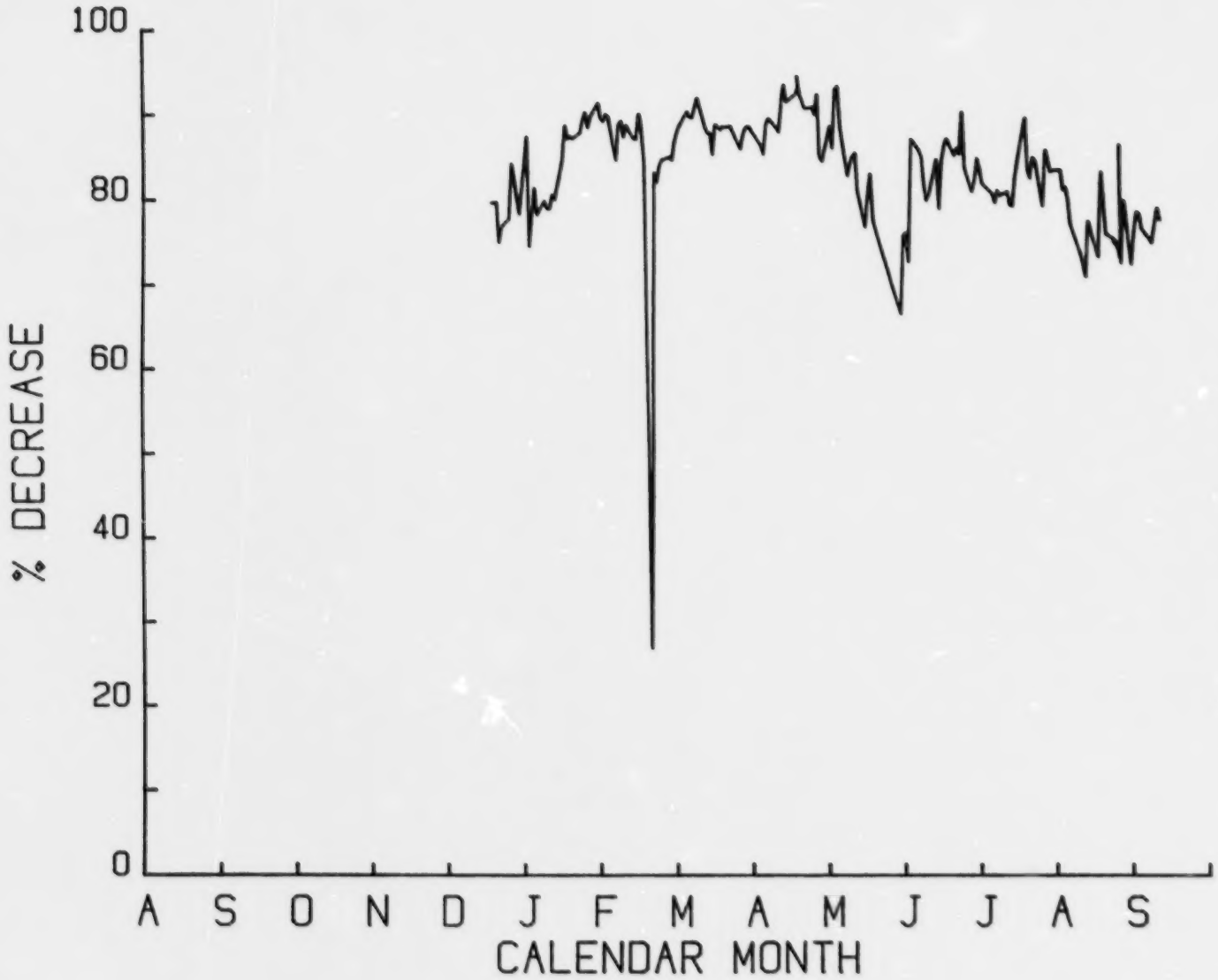

Fig. 5. Relative decrease of chlorine between Stn 3 and Stn 4, 1985/86.

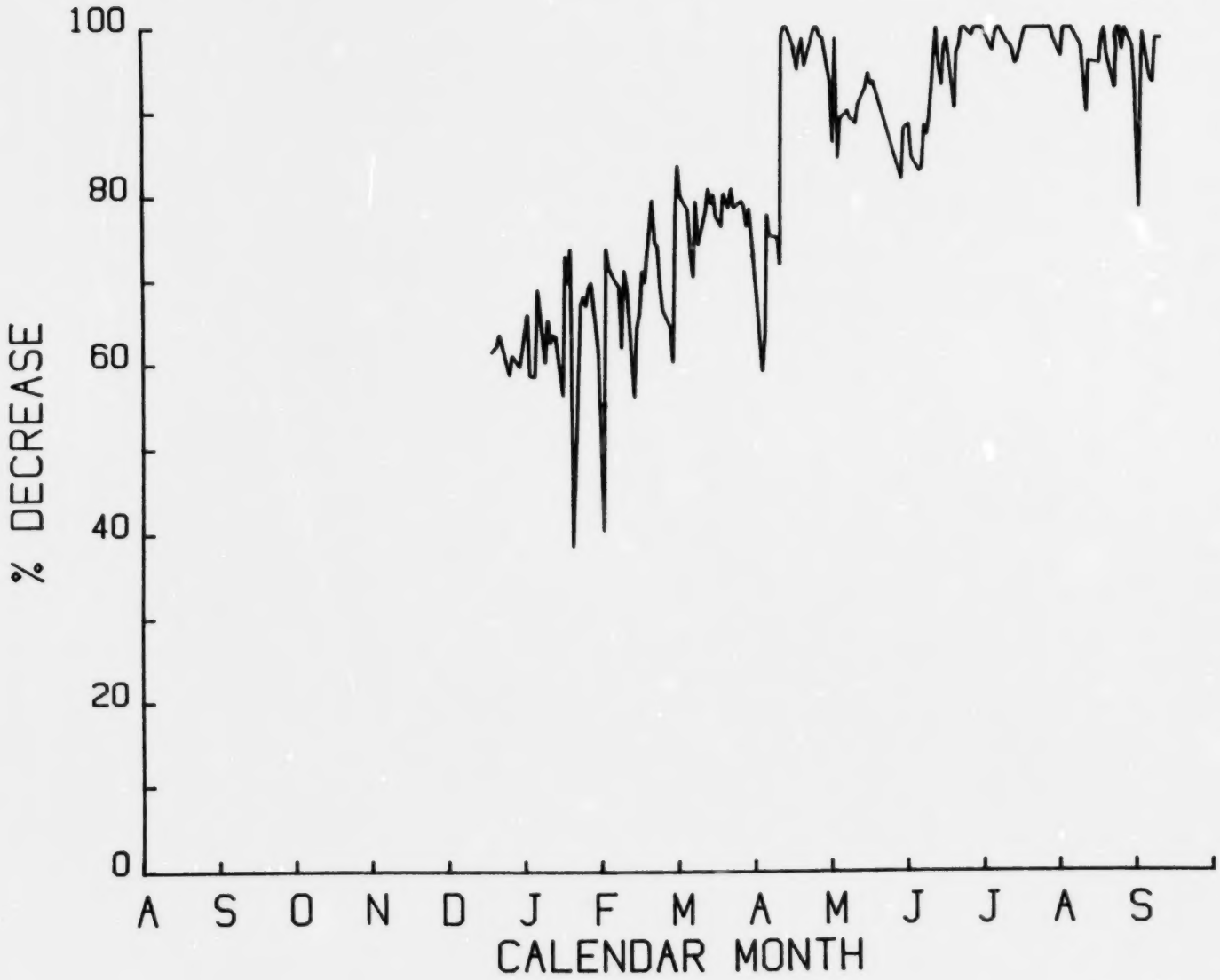

Fig. 6. Relative decrease of chlorine between Stn 4 and Stn 9, 1985/86.

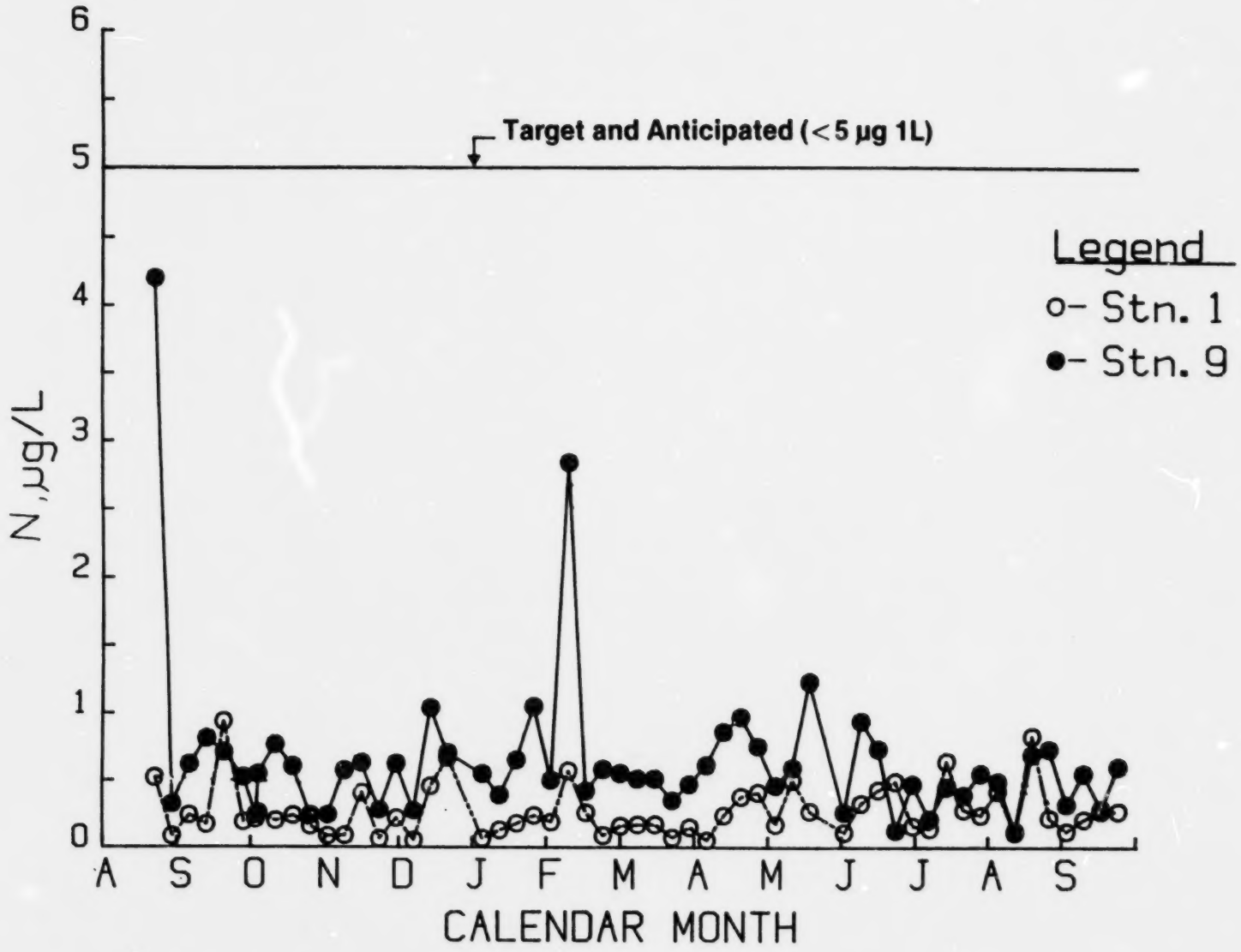

Fig. 7. Non-ionized ammonia (NH_3) in product water (Stn 9) and City water (Stn 1), 1985/86.

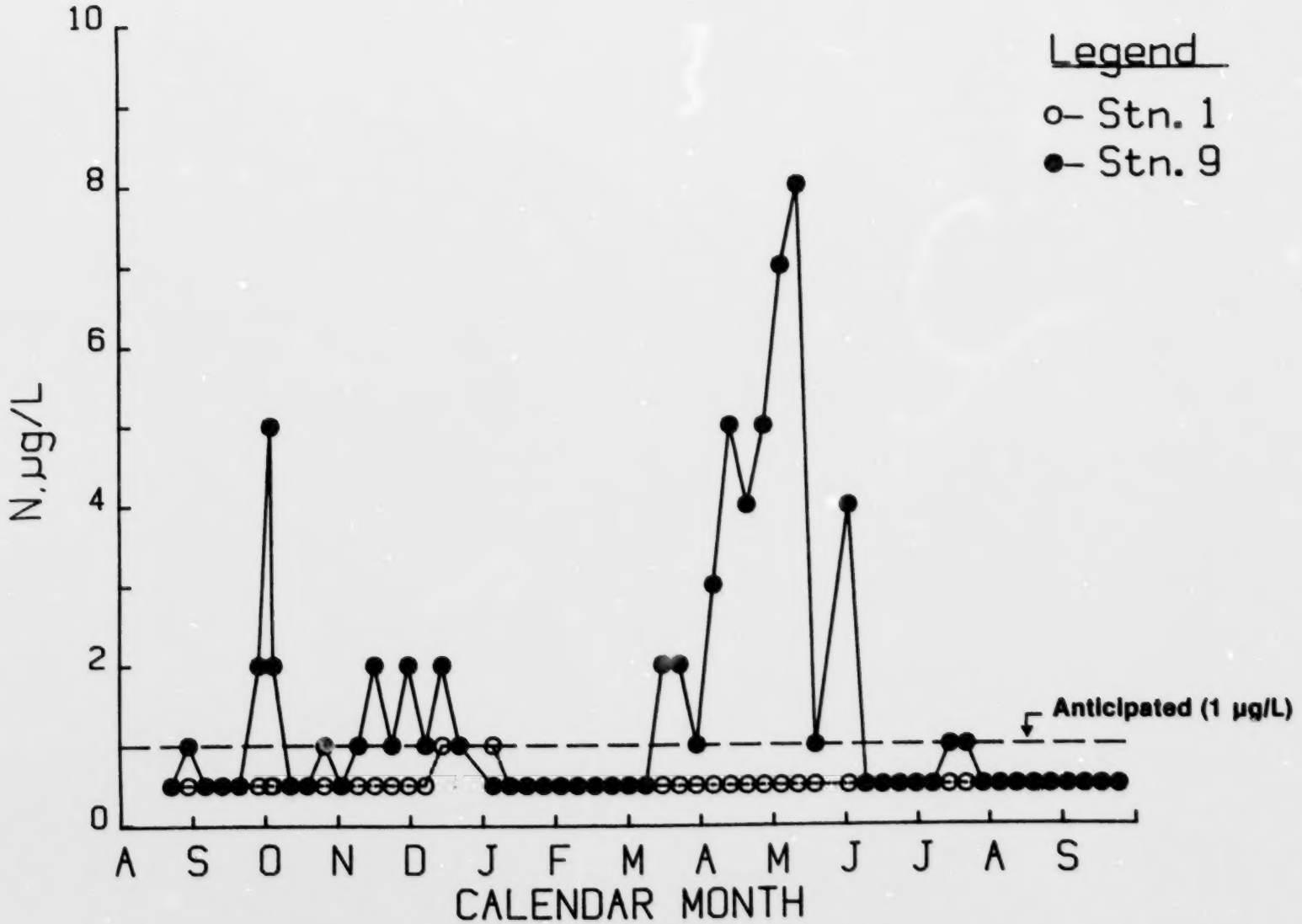

Fig. 8. Nitrite (NO_2) in product water (Stn 9) and City water (Stn 1), 1985/86.

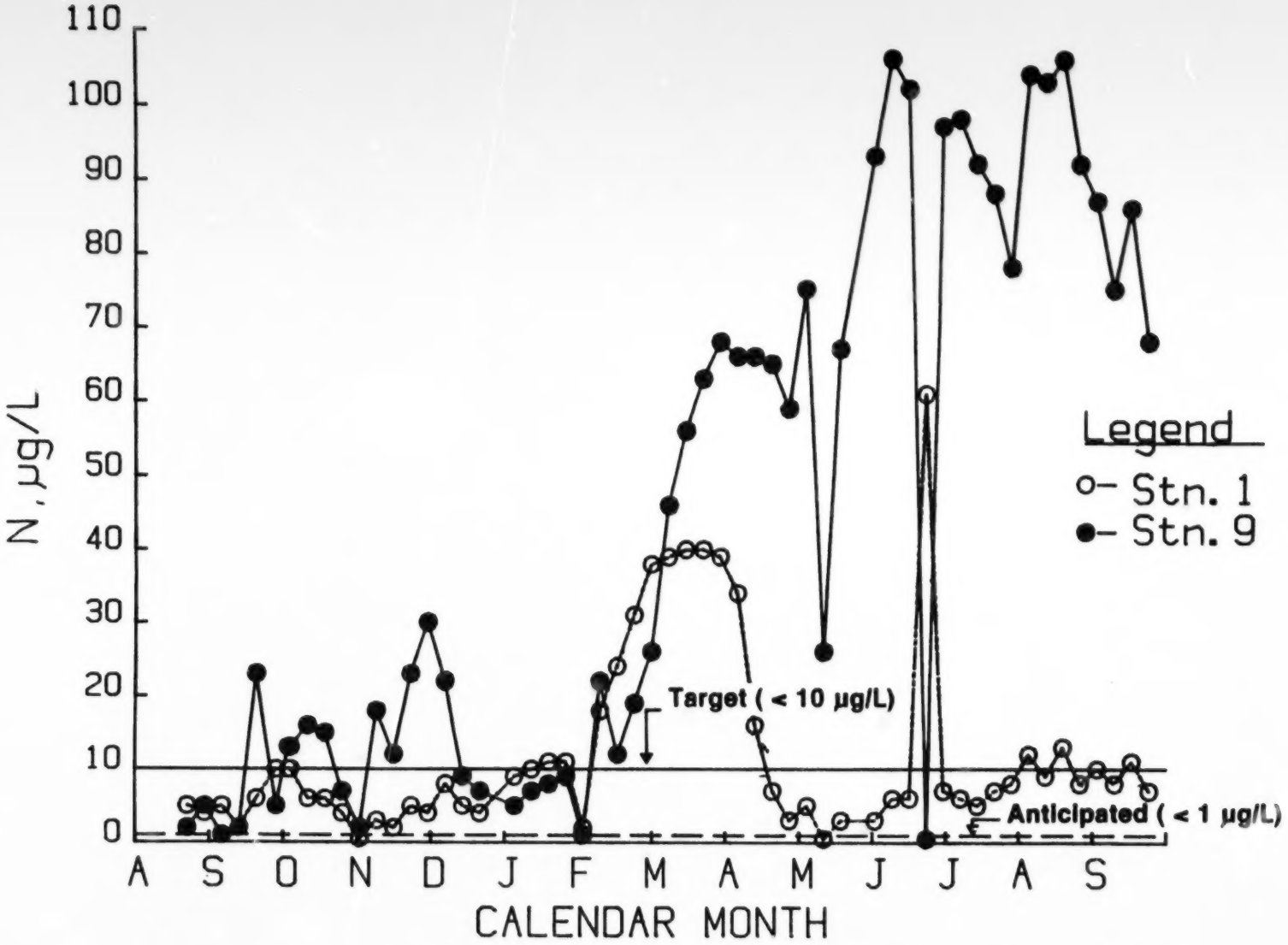

Fig. 9. Nitrate (NO_3) in product water (Stn 9) and City water (Stn 1), 1985/86.

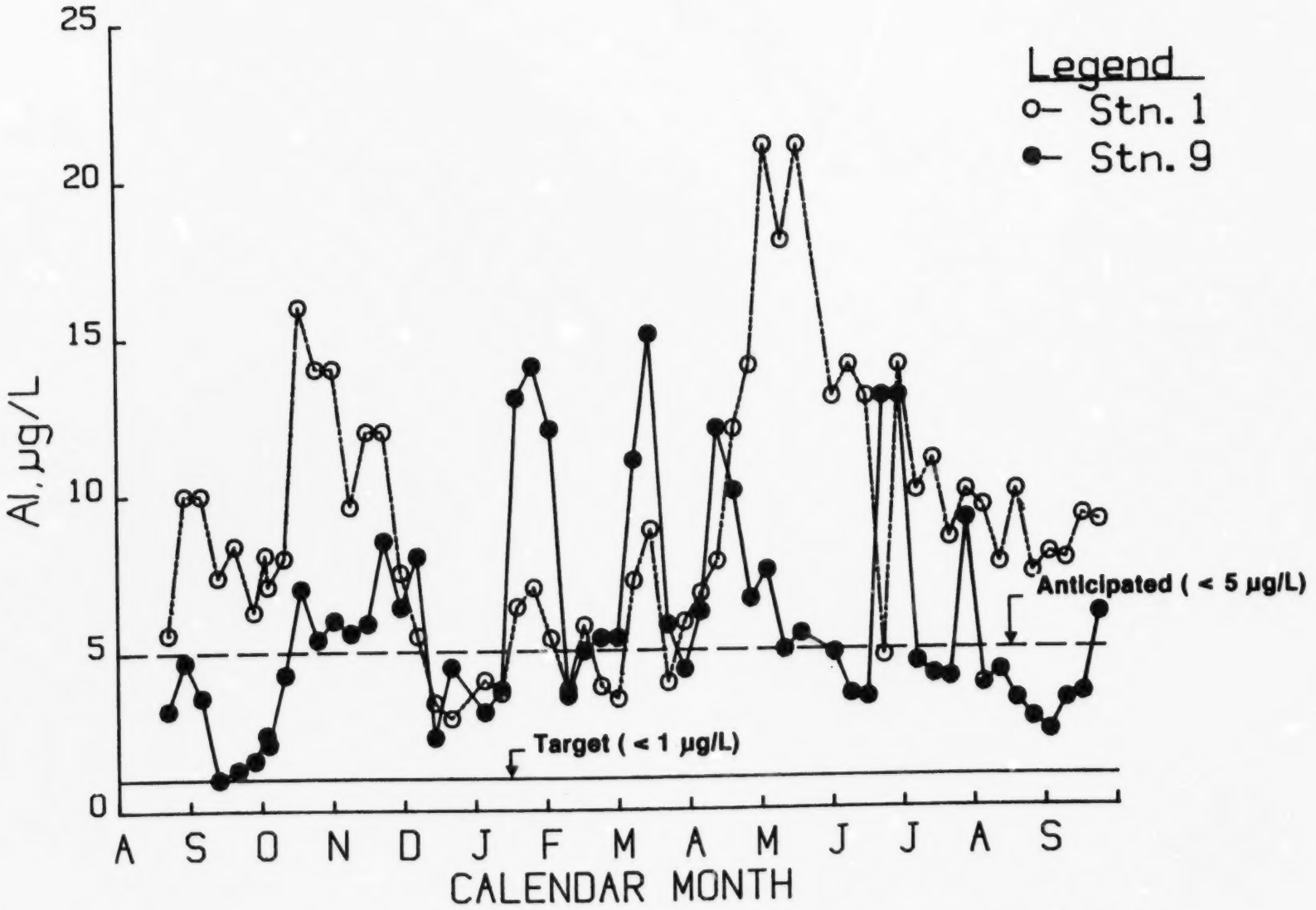

Fig. 10. Total dissolved aluminum (Al) in product water (Stn 9) and City water (Stn 1), 1985/86.

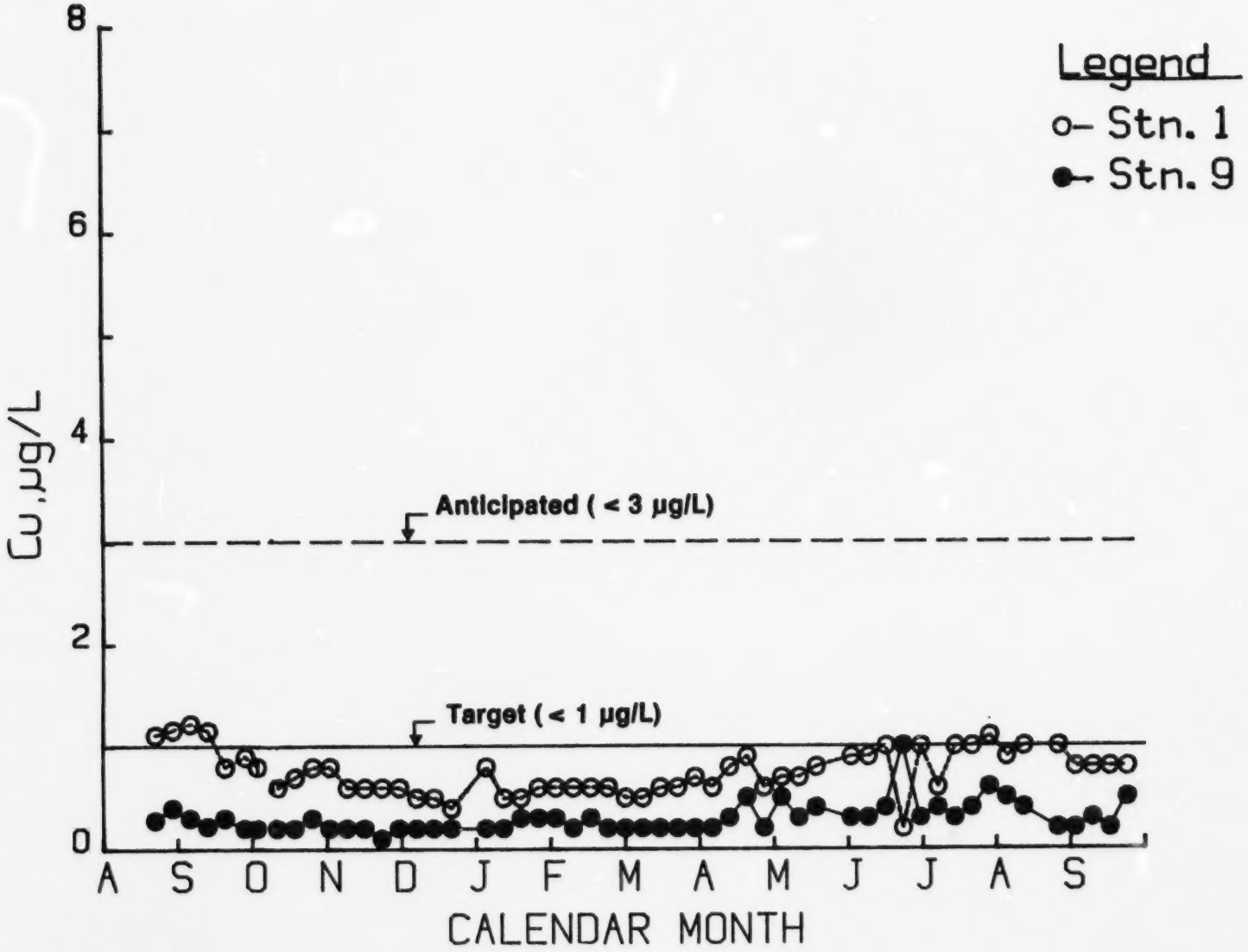

Fig. 11. Total dissolved copper (Cu) in product water (Stn 9) and City water (Stn 1), 1985/86.

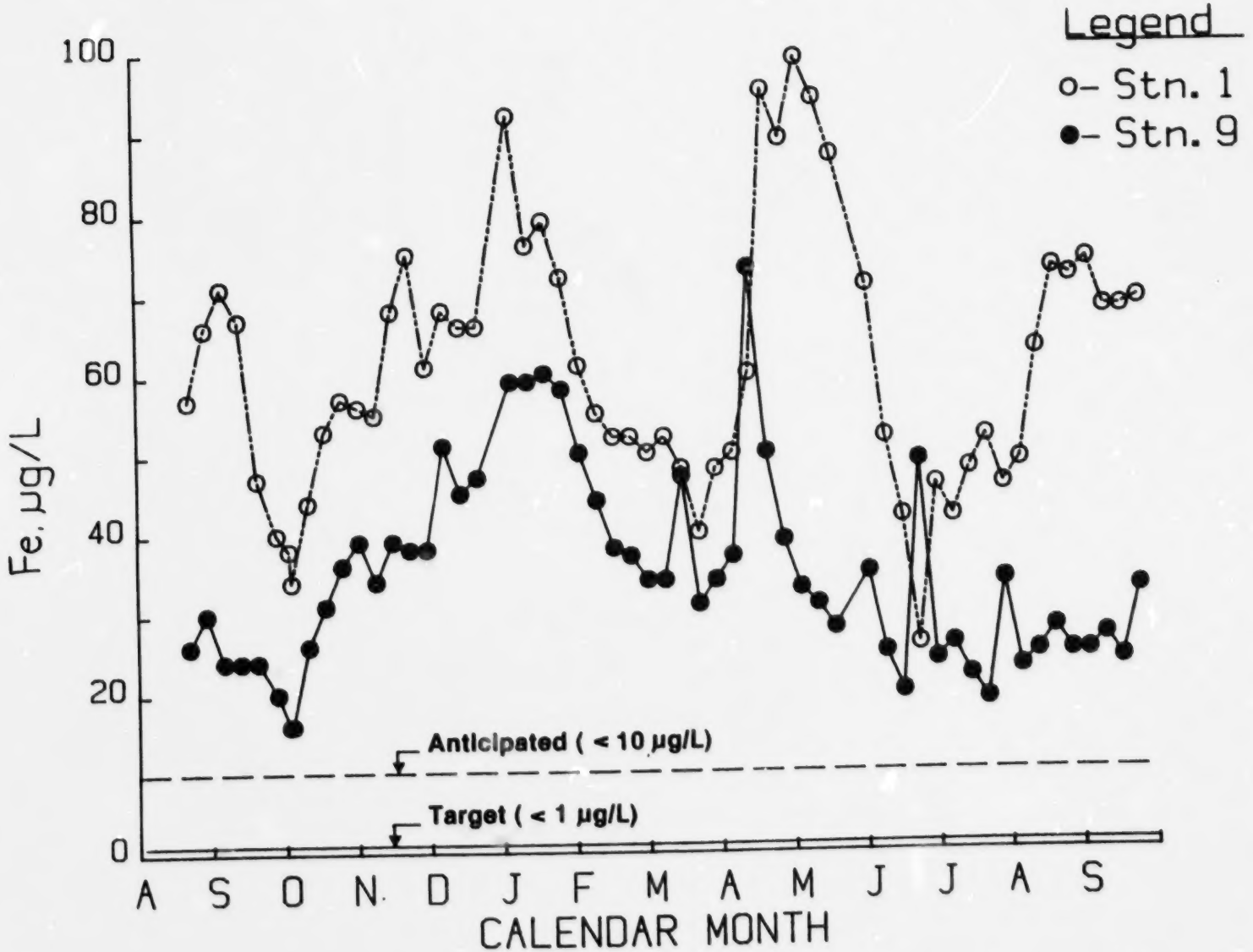

Fig. 12. Total dissolved iron (Fe) in product water (Stn 9) and City water (Stn 1), 1985/86.

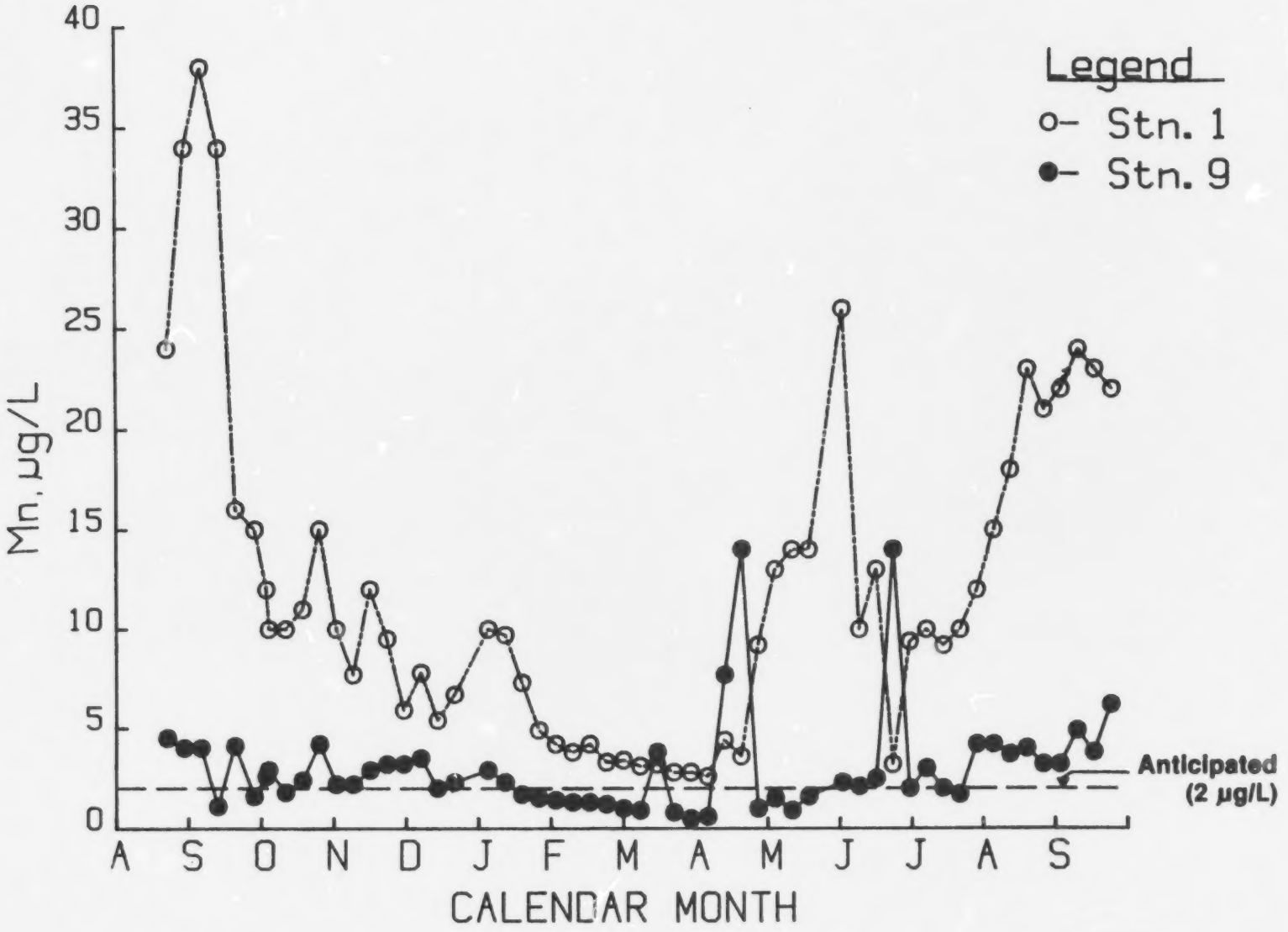

Fig. 13. Total dissolved manganese (Mn) in product water (Stn 9) and City water (Stn 1), 1985/86.

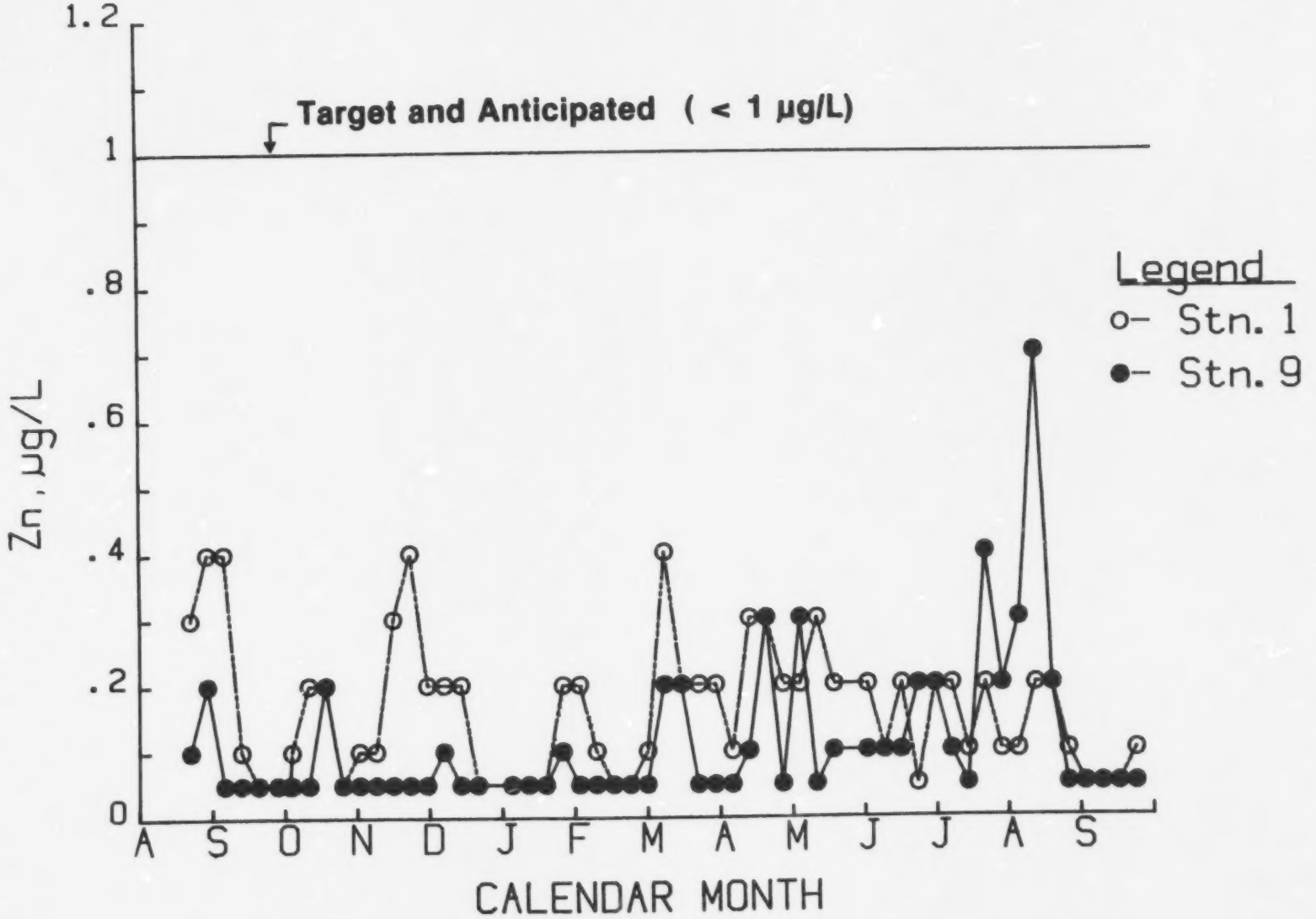

Fig. 14. Total dissolved zinc (Zn) in product water (Stn 9) and City water (Stn 1), 1985/86.

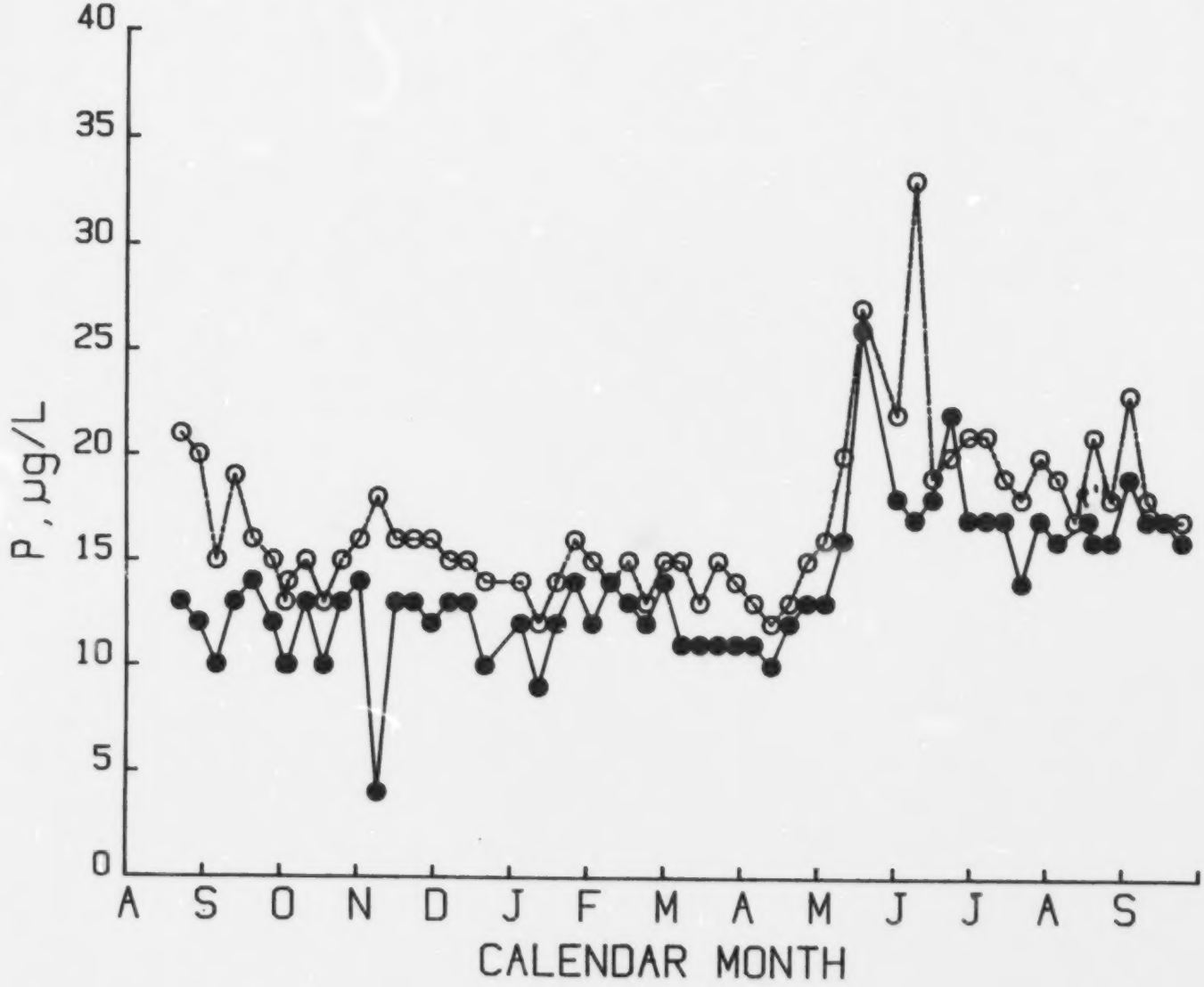

Fig. 15. Total dissolved phosphorus (P) in product water (Stn 9) and City water (Stn 1), 1985/86.

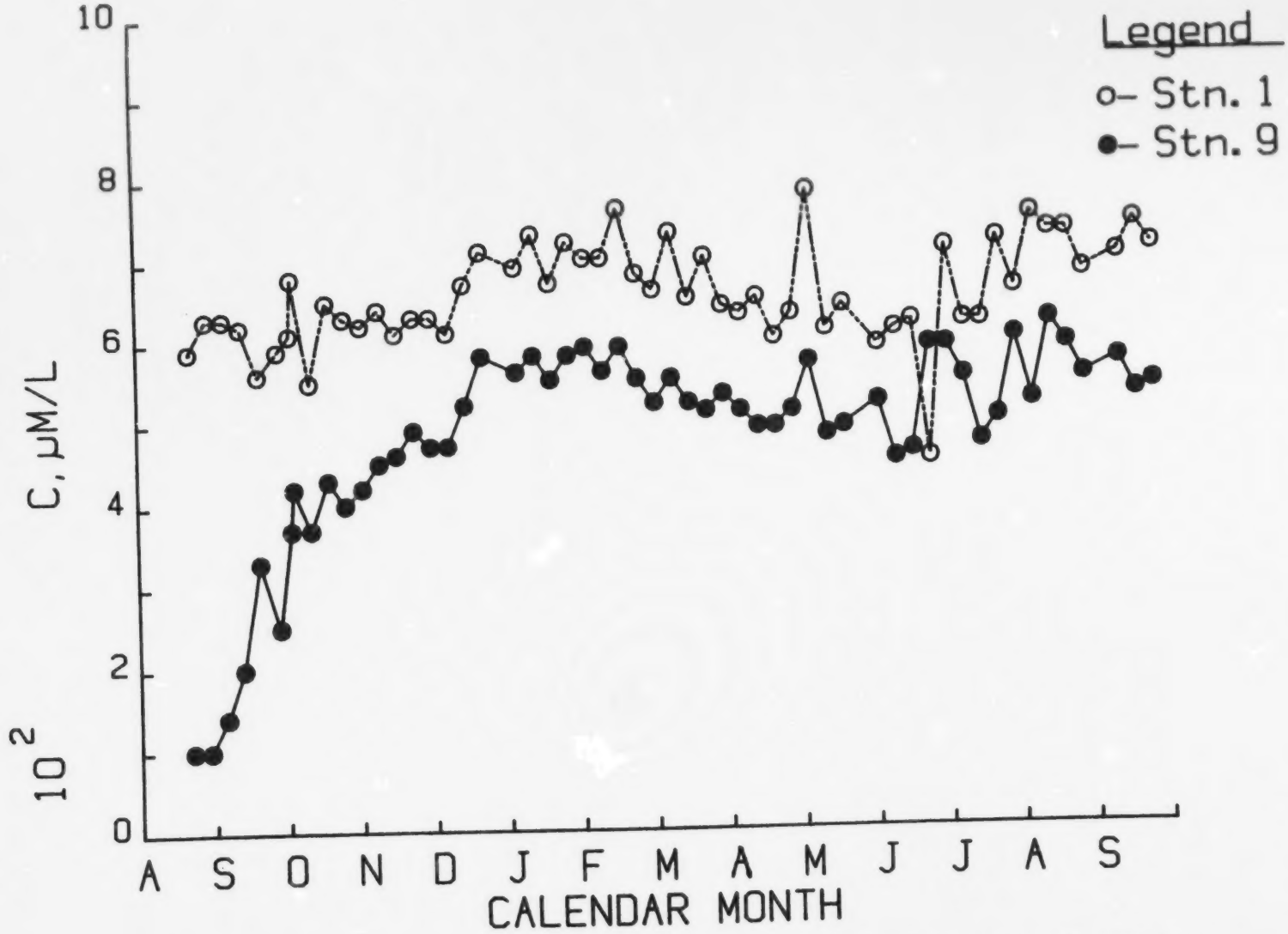

Fig. 16. Total organic carbon (C) in product water (Stn 9) and City water (Stn 1), 1985/86.

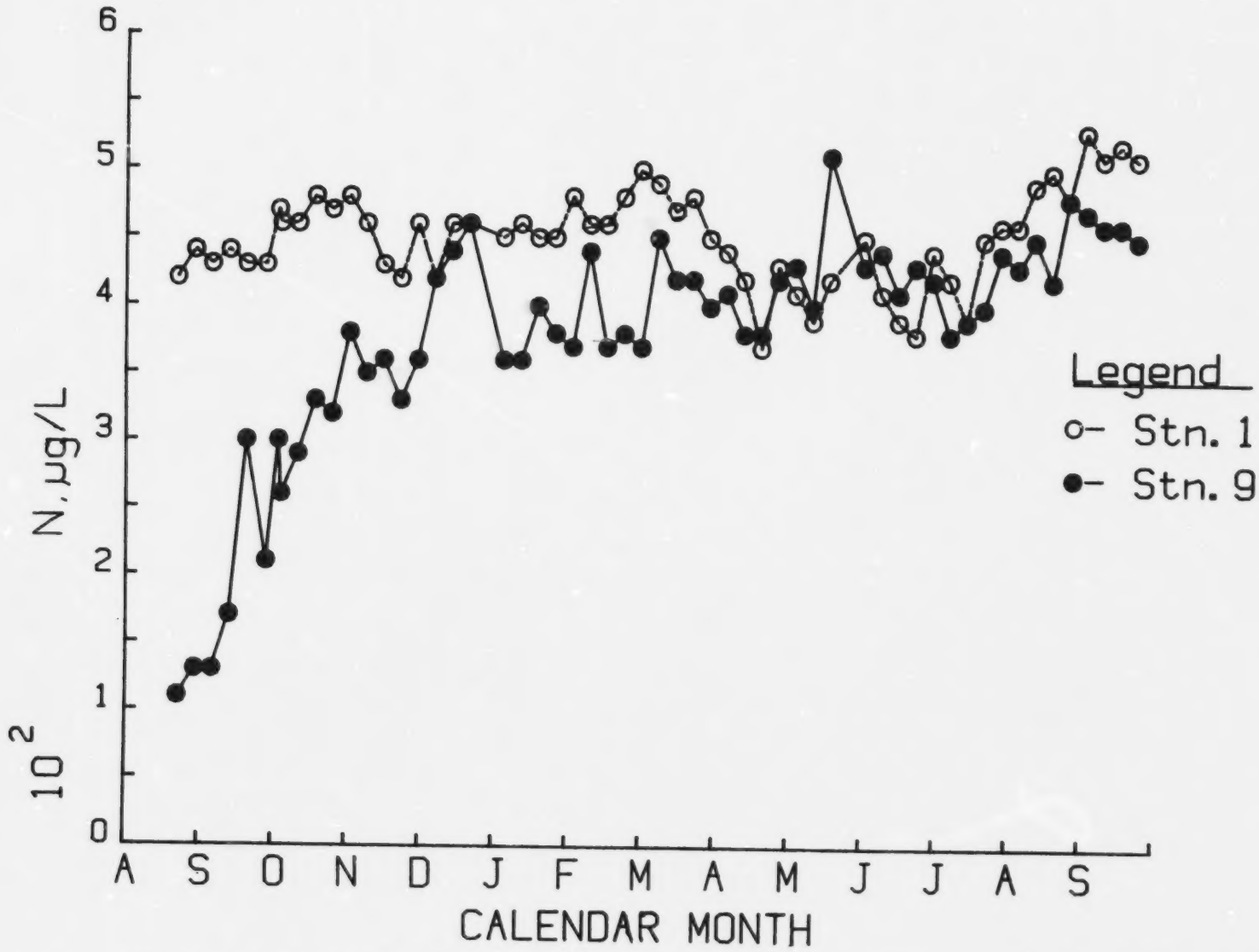

Fig. 17. Total dissolved nitrogen (N) in product water (Stn 9) and City water (Stn 1), 1985/86.

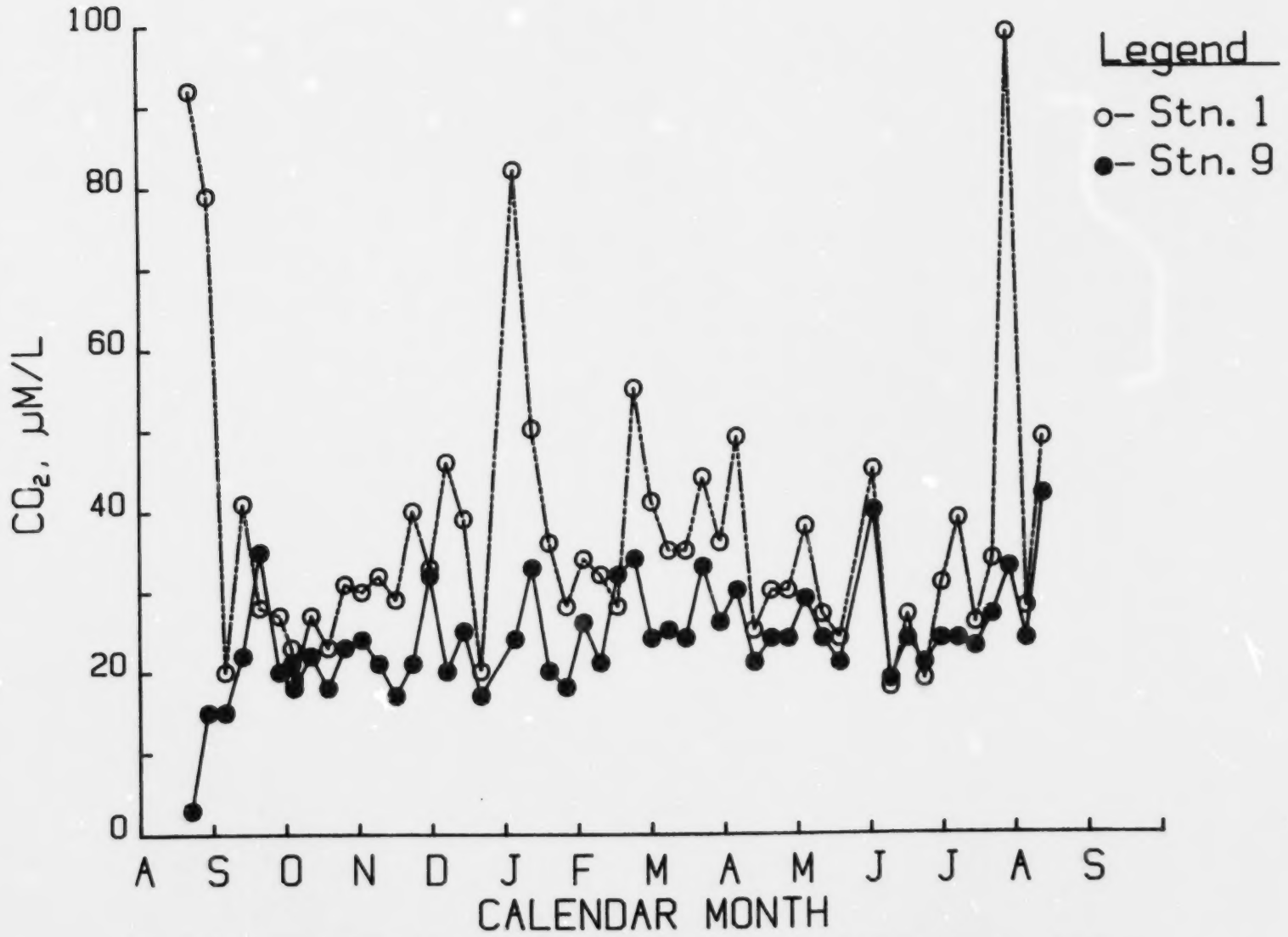

Fig. 18. Carbon dioxide (CO_2) in product water (Stn 9) and City water (Stn 1), 1985/86.

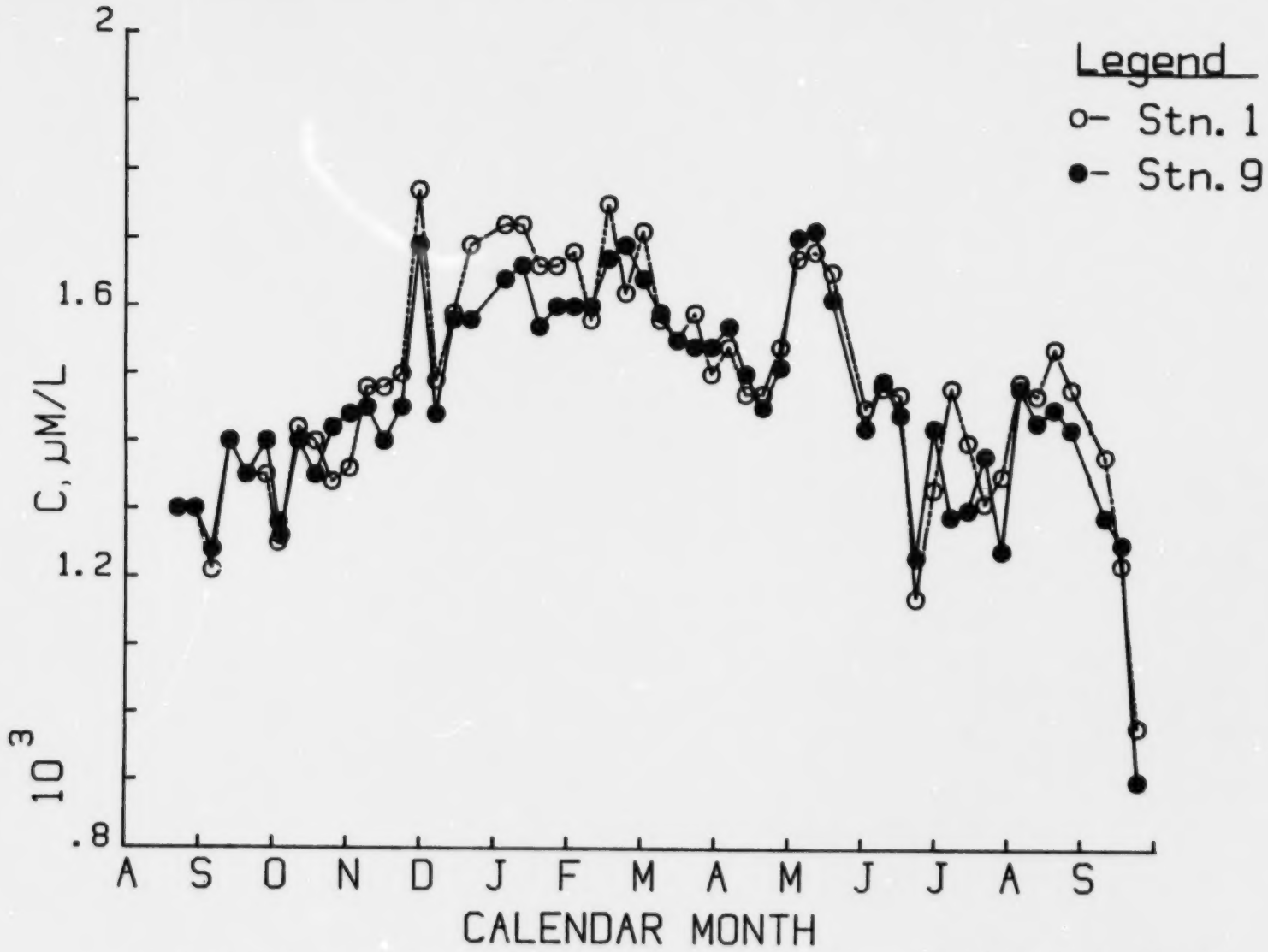

Fig. 19. Dissolved inorganic carbon (C) in product water (Stn 9) and City water (Stn 1), 1985/86.

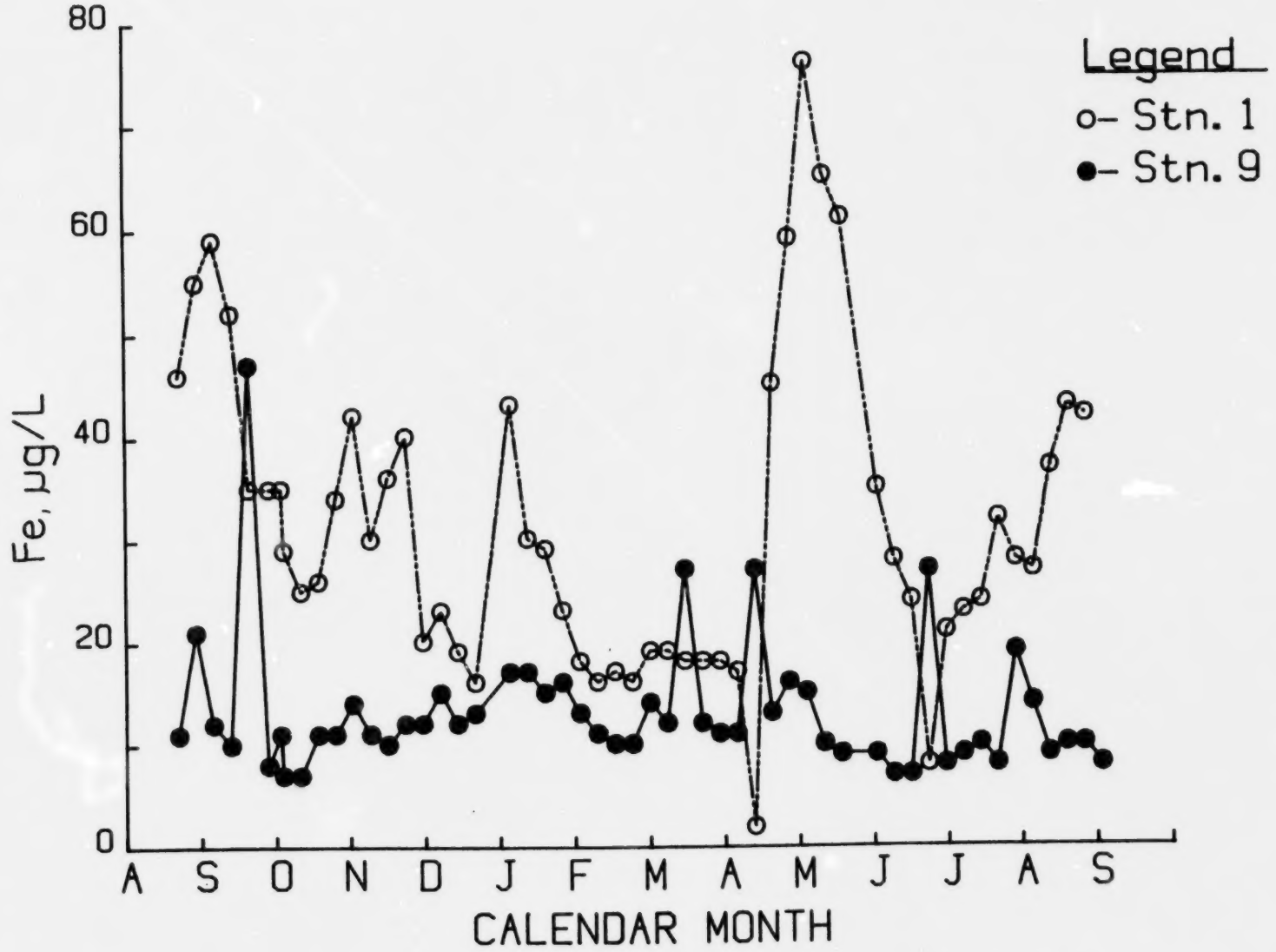

Fig. 20. Suspended iron (Fe) in product water (Stn 9) and City water (Stn 1), 1985/86.

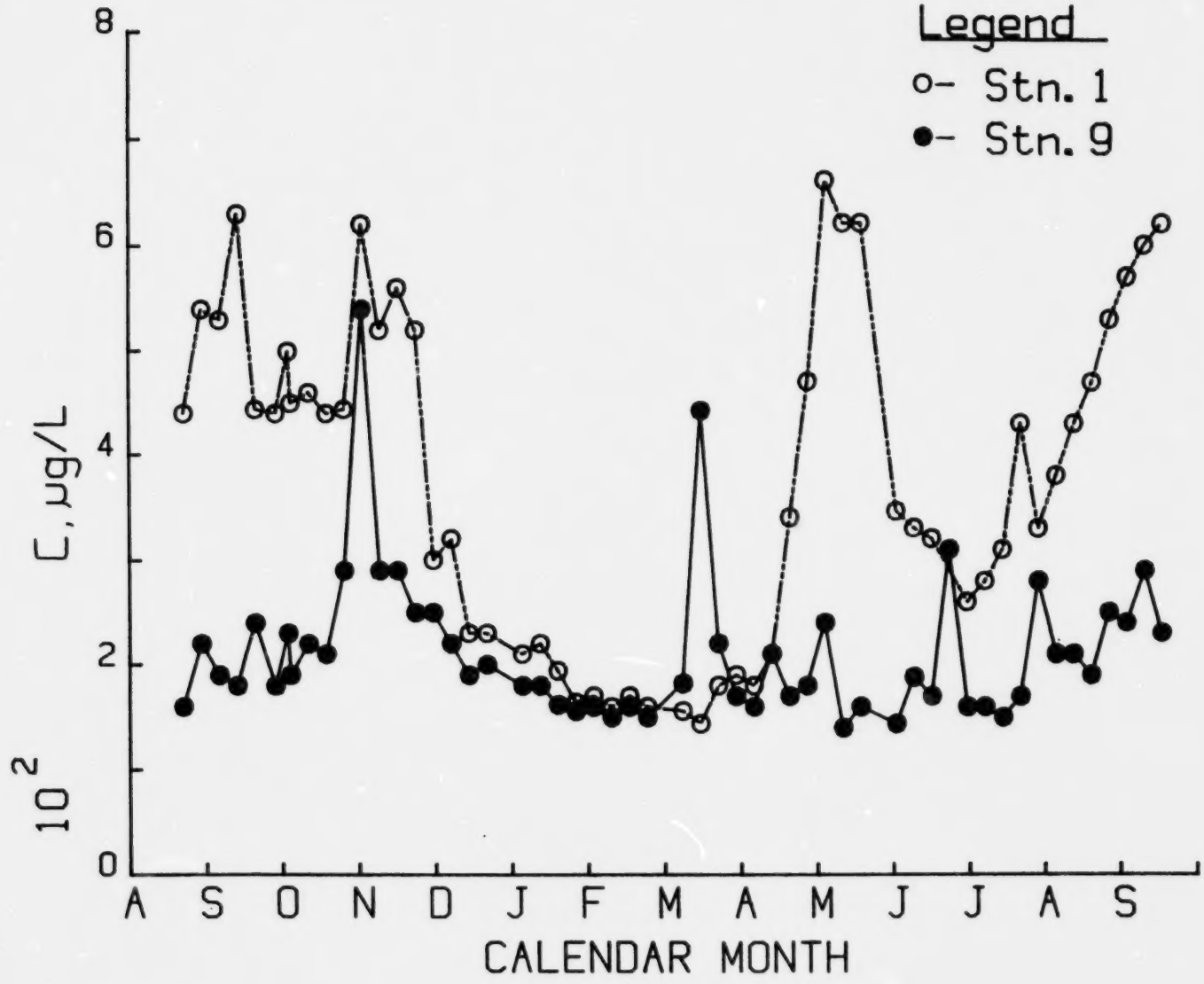

Fig. 21. Suspended carbon (C) in product water (Stn 9) and City water (Stn 1), 1985/86.

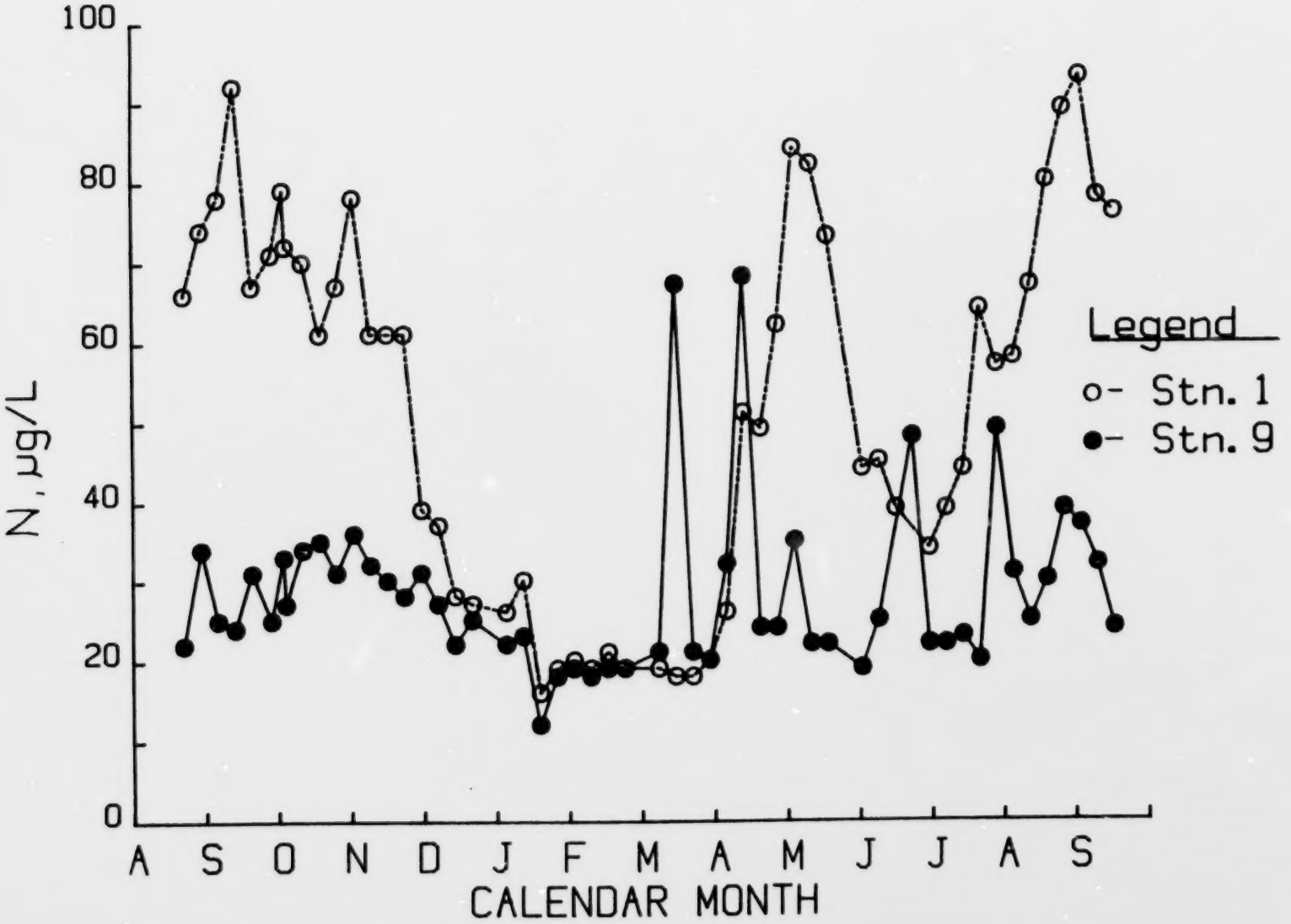

Fig. 22. Suspended nitrogen (N) in product water (Stn 9) and City water (Stn 1), 1985/86.

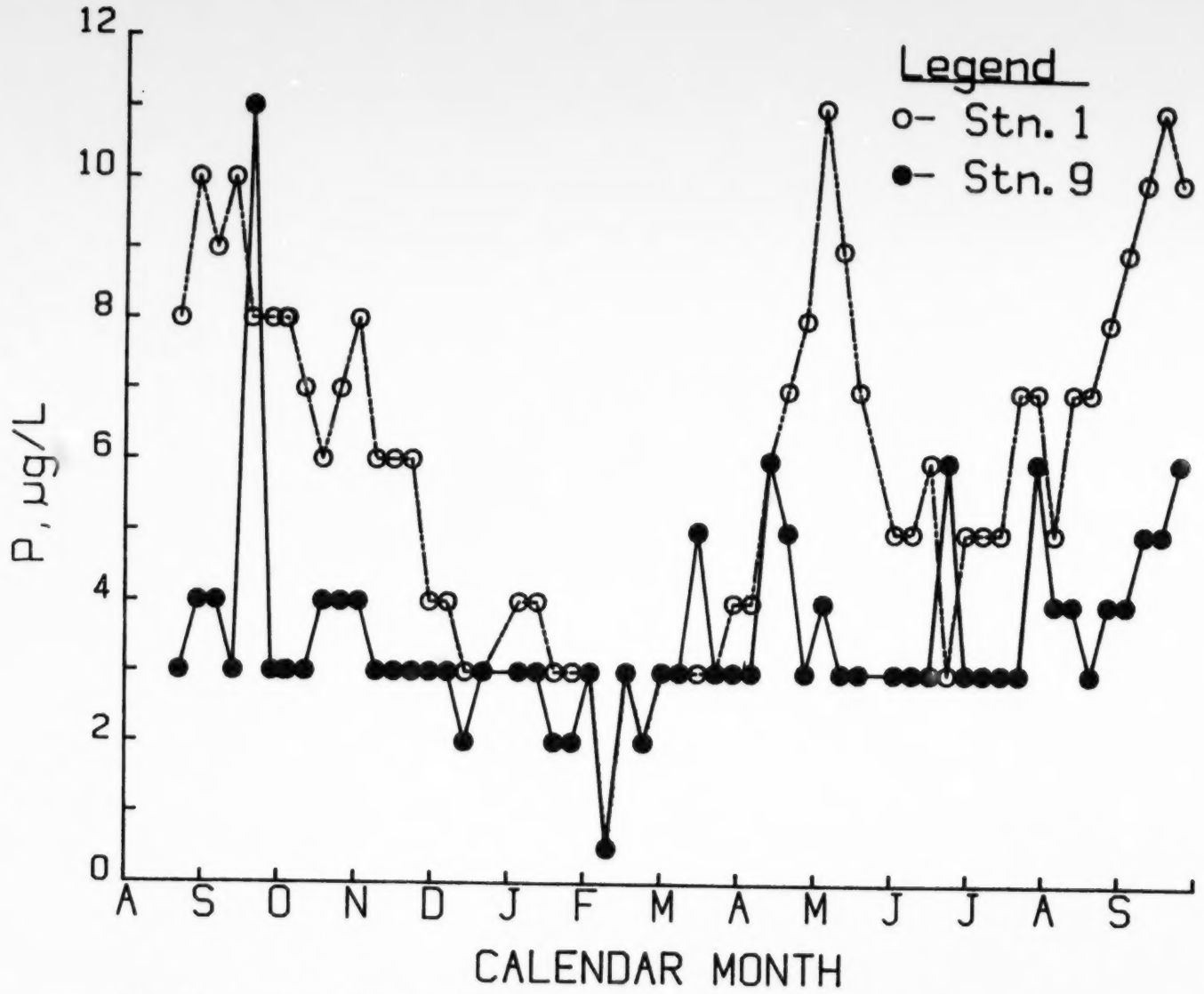

Fig. 23. Suspended phosphorus (P) in product water (Stn 9) and City water (Stn 1), 1985/86.

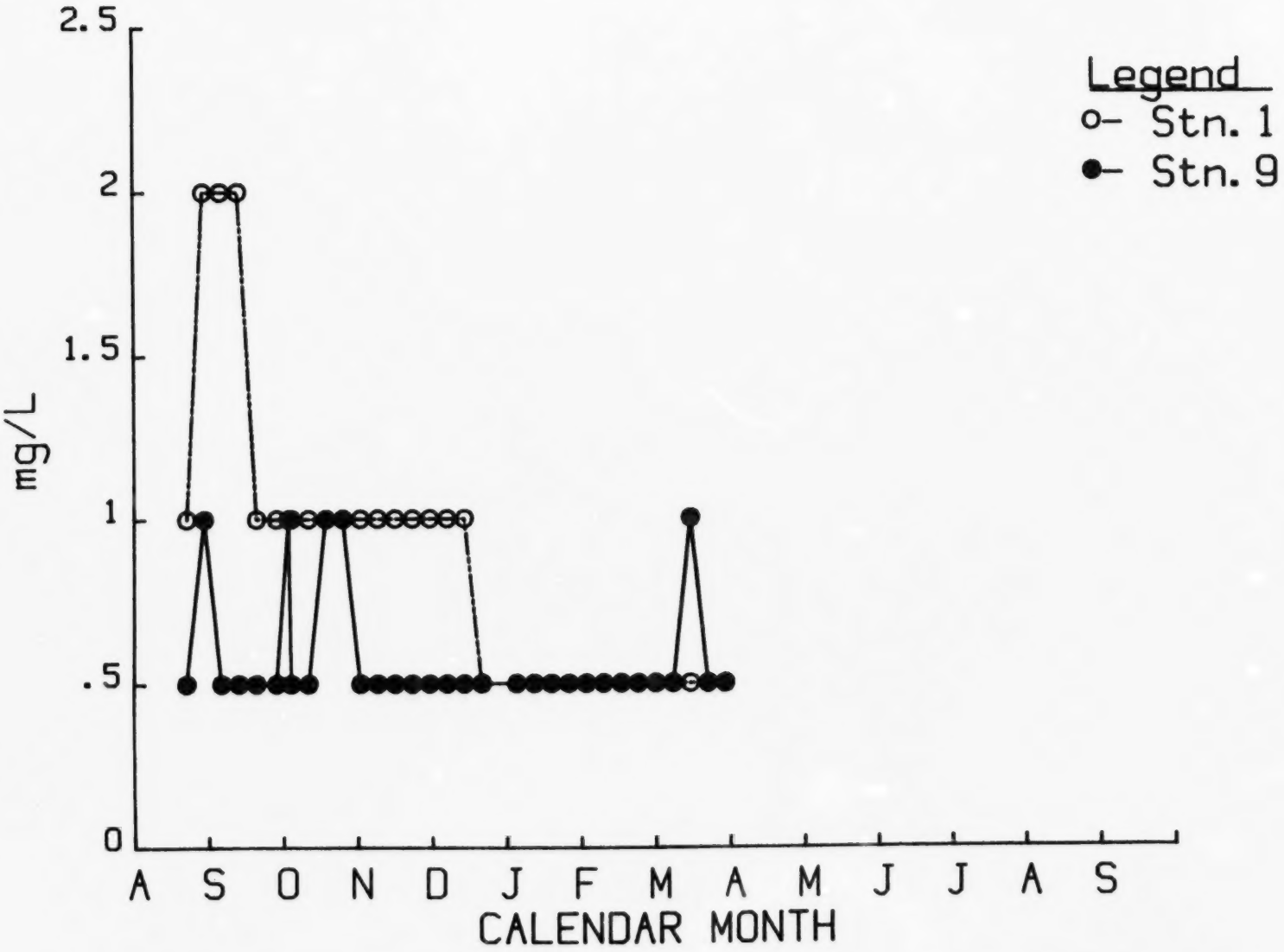

Fig. 24. Total suspended solids in product water (Stn 9) and City water (Stn 1), 1985/86.